REPORT
JULY 2020

Scaling Up Electric Vehicle Charging Infrastructure

LESSONS FROM CHINA AND THE UNITED STATES FOR THE INDIAN CONTEXT

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Project Directors: Anjali Jaiswal, Simon Mui and Mona Yew
Project Researchers: HyoungMi Kim and Charu Lata
Contributing Researchers: Rajkiran Bilolikar, Akhilesh Magal, Nicole Lepre, and Jessica Korsh

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Report Summary

A widespread, accessible public charging infrastructure network is needed to support a robust electric vehicle (EV) market – as evidenced by experiences in China, the United States, and around the world. In India, EV sales need to reach 30% for private cars, 70% for commercial cars (i.e. delivery vehicles, fleets, and taxis), 40% for buses and 80% for two and three-wheelers by 2030 to advance electric mobility, according to analysis by the Indian government.[1] An aggressive scale-up of charging infrastructure across India is needed to achieve these EV sales goals.

Source: iMahesh, Creative Commons

To expand India's charging infrastructure, this report provides best practices from two of the largest EV markets – China and the United States – for the Indian context. This report aims to provide Indian policymakers and stakeholders with a review of the key challenges facing EV charging infrastructure markets in China and the United States. It also provides examples of strategies that government agencies, utilities, charging service providers, and automakers are deploying to overcome challenges. Each section starts with an overview of the Indian EV market and charging infrastructure for context. An overview of EV charging infrastructure in China and the United States is provided, including sections on the current level of deployment, targets for filling the infrastructure gap, discussion of funding and investment sources, technologies and a summary of the key barriers and opportunities facing EV infrastructure expansion.

India EV and Charging Infrastructure Overview

Electric mobility in India has been dominated by two and three-wheelers for the past decade.[2] Electric two-wheelers (scooters, motorcycles) and the largest commercial three-wheelers (rickshaws, good carriers) reached 242,000 units sold in FY2020 or about 1% of the market.[3] City, state and national programs are also increasing EV bus fleets for public transportation.[4]

Unlike China and the U.S., where four-wheelers (automobiles) make up a large share of the market, India's electric four-wheeler market is nascent, with just 4,000 sold or less than 0.14% share in 2020.[5] For automobiles, India had a total of 1,332 public charging stations in 2019.[6] To accelerate electric mobility, the Government of India's scheme Faster Adoption and Manufacturing of Electric and Hybrid Vehicles (FAME II) created growth opportunities for EVs and charging infrastructure with an initiative to install 2,636 charging stations in 62 cities across 24 states and union territories in 2020.[7] Funding sources for the Indian EV market include national, state programs as well as private sector investments, see Figure 1. While the COVID-19 economic downturn will likely slow the short-term EV market growth, opportunities for long-term growth remain positive.[8] According to economic experts, an estimated 4 million

electric two-wheelers and three-wheelers are projected to be sold in India by 2025.[9] India is also still planning to bring an additional 2,600 EV charging stations online with more expected by 2025.[10] Yet, key challenges, such as funding availability and market sector adoption, remain.

Figure 1: Funding Sources for the Indian EV Market (Source: NRDC, 2020)

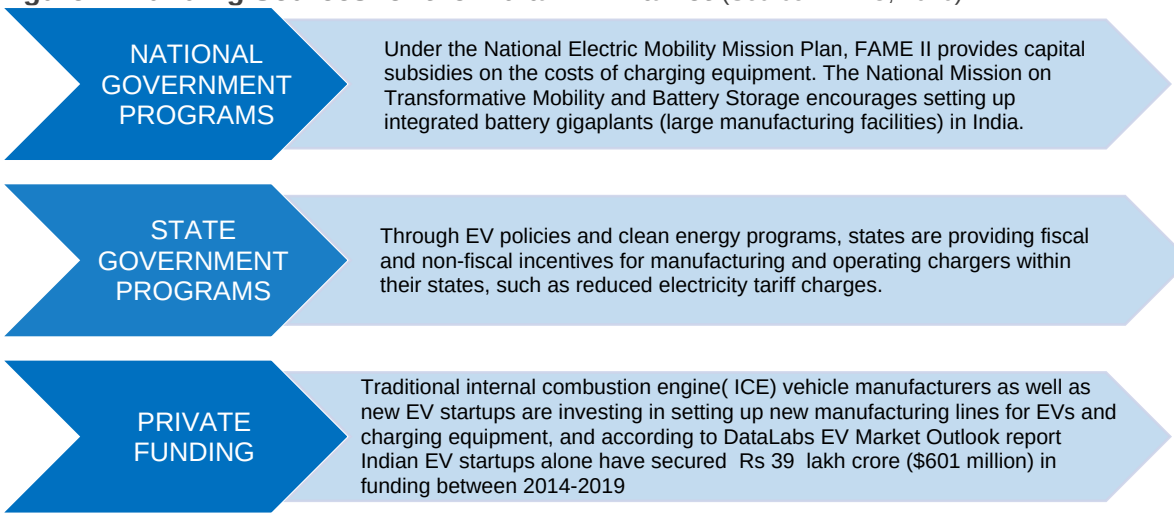


Figure 1 represents India's identified public and private funding sources.[11]

Charging Infrastructure Challenges

Today, the economics of charging infrastructure and installation remains unfavorable or weak. As seen in China and the U.S., strong government support, coupled with utility-EV focused programs, is necessary to create a foundation for additional private investments.[12]

Barriers to establishing charging infrastructure in apartment complexes and commercial building complexes also remain challenging in India as well as the U.S. and China. With most people in Indian cities living in apartment complexes, solutions need to ensure the availability of dedicated parking spaces for EV charging. As in the U.S., Indian government officials and municipal leaders are now considering revising building by-laws to ensure that all new buildings are EV-infrastructure ready. To advance the market, cooperative solutions, such as those in China, are also needed to facilitate the necessary coordination between property owners of apartment and commercial building complexes, EV owners, and infrastructure providers.

The lack of harmonization around EV charging standards continues to add costs and barriers to establishing a ubiquitous national charging infrastructure network. Currently, India has not standardized requirements on private or public charging infrastructure and, like the U.S., has allowed numerous charging connector standards to be utilized by automakers. This means that charging stations may provide one, some, or all connector options (Bharat charger AC001, DC001, CHAdeMO, CCS and GB/T) to EV users on a common board or charging kiosk. China, which faced similar challenges initially has now developed and instituted national standards to ensure uniformity across the market.[13] Ultimately, the lack of standardization in India and the U.S. could lead to operability challenges, reduced public access, decreased utilization of charging infrastructure, and overall higher costs for electric transportation.

COVID-19 Implications for EVs

With the COVID-19 pandemic, governments around the world are working to protect public health and safeguard economies. Preliminary results from many global studies show that elevated levels of air pollution can weaken the respiratory system's ability to fight infections, and higher particle air pollution concentrations are correlated with higher death rates from COVID-19.[14] Electric vehicles and investments in infrastructure can help overcome these challenges in India on two fronts. First, when coupled with increased renewable generation, electric vehicles can significantly reduce air pollutants from the transportation sector.[15] Second, regional economic growth can be simulated from investments in electric transportation through direct, indirect, and induced job creation associated with electric vehicle and battery manufacturing, charging infrastructure, electricity distribution upgrades, and electricity generation.[16] Combined with the large fuel and maintenance savings from EVs, fleets and the public can decrease transportation costs over time – savings that can be reinvested into the economy.

Key Takeaway Summary – China and United States

Based on a review of the policies and practices in China and the United States, key lessons for the Indian context for the deployment of charging infrastructure include:

By the Numbers: Charging Infrastructure Deployment

China

- China currently has the world's largest EV charging infrastructure network.[17]
- State-owned utilities play a critical role in establishing the majority of public charging infrastructure in China. However, in recent years, private companies have become major investors and account for a greater share of new installations. Even with the growth of the private sector market, state-owned utilities in some cases, are providing financing for companies that implement charging infrastructure.[18]
- Nearly 40% of chargers are public, with the remaining 60% for private use in China.[19]
- Most public ports are not evenly distributed across China and are highly concentrated in a few of the largest cities, which also tend to have more robust EV programs and larger vehicle markets.[20]
- China's vehicle-to-charging port ratio has improved, such that on average, for every 3.5 electric vehicles, there is now one charger (including public buildings and apartment complexes) with some jurisdictions approaching a one to one ratio.[21]
- The vehicle-to-charger ratio is much lower in China than in the U.S. because a higher proportion of Chinese residents live in apartment complexes and need access to public and apartment complex chargers.
- Larger cities in China, such as Beijing, Shanghai, and Guangdong or "Tier 1 cities," generally provide stronger support for the construction of private charging ports. These cities have focused on advancing cooperative models for apartment buildings to bring together property managers, EV owners, and private charging infrastructure providers.[22]

United States

- California currently has the most developed EV market in the U.S.[23]
- In the U.S., most of the initial EV owners live in detached, single-family households with a garage and most EV drivers in the U.S. are charging at home, followed by workplaces, and public charging stations.[24]
- Public charging in the U.S. has recently increased rapidly to reduce "range anxiety" among EV drivers and to expand the ability to utilize EVs for long-range trips.[25]
- The appropriate ratio of public chargers to EVs is somewhat uncertain, with some studies suggesting that a 3:1 or 10:1 EV to charger ratio (public, workplace, and apartment complexes) ratio may be appropriate.[26]

Gaps in Public and Private Charging Needs

China

- Currently, the majority of EVs that have been sold are owned by consumers with access to their own private (home) charging in China.
- Additional charging infrastructure at apartment complexes and public charging stations is needed to reach a large part of the EV market who cannot charge at home and to enable widespread transportation electrification.
- Policies are being enacted to help overcome obstacles and barriers at apartment complexes, including cooperative models between property owners, residents, and infrastructure providers.
- Public charging infrastructure is increasing but the current utilization rate is low, suggesting that the siting of this infrastructure is sub-optimal.
- Consolidation within the charging infrastructure industry is occurring as smaller-sized companies are either merging or exiting the market. Together with shared platforms or apps, this consolidation may improve the economics and customers' experience.
- Ride-hailing services present a large opportunity for broader EV market adoption.

United States

- The majority of EV charging sites are residential since home charging is more straightforward in the U.S.
- To expand the EV market, states and cities are adopting policies to expand public charging access, workplace charging, and private access in apartment complexes.
- Key public charging locations include retail sites, curbside locations, and highway corridors in the U.S.
- Highway corridors are important sites for charging stations, particularly DC fast charging stations, to allow EV drivers to make longer trips and to relieve range anxiety (fear that a vehicle has insufficient range to reach its destination).
- Curbside charging locations are becoming increasingly important in urban settings where private and public parking is limited, and to provide charging for drivers who live in apartment complexes without charging access.
- Government-owned fleets may also benefit economically from vehicle electrification and infrastructure due to lower ownership costs of EVs.
- Electrification for ride-hailing and taxis may be particularly cost-effective given the potential for larger savings on fuel costs. Lyft, the second-largest ride-hailing company, based in the U.S., recently announced their plans to electrify their platform by 2030.[27]

Funding Sources for Charging Infrastructure

China

- Charging infrastructure development has been heavily supported by government investments, including through state-owned utilities together with national and local-level incentive programs and policies.[28]
- Governments and policymakers have increasingly opened the market to facilitate greater private investments in charging infrastructure, leading to growth in the number of charging infrastructure providers and overall investment levels.
- National directives have helped establish and promote the current charging infrastructure ecosystem. Programs, such as incentive funds for charging infrastructure, EV charging fee programs, and cooperative models between property managers at apartment complexes, have helped improve the operation of charging facilities.
- Many local governments have established complementary programs to the national directives. The local programs and incentives are based on different project factors, such as total investment, the power capacity of charging points, or fixed amounts.
- Utilities have made significant investments in charging infrastructure, largely aligned with national level directives. The utility investments have come from companies' social responsibility budgets or are made through a separate EV infrastructure entity. The utilities have built an intra-city network of charging stations to connect cities.
- Utilities are increasingly looking to invest in EV infrastructure as an attractive business opportunity. They have been among the first to install charging infrastructure and provide charging services and utilities have begun to make necessary grid upgrades to support charging infrastructure deployment.
- Automakers and energy companies are investing in acquisitions and joint ventures. Private investments are helping fill the gap in non-highway based public and private charging infrastructure.

United States

- In response to the global recession in 2009, the U.S. Congress passed the American Recovery and Reinvestment Act (ARRA), which provided funding to support vehicle electrification efforts, including an estimated 18,600 home, public, and commercial charging points.[29]
- Since then, federal and state governments – through various programs - have continued to be a large source of funding for charging infrastructure.
- Electric utilities are now becoming one of the largest investors through their EV-utility programs, many of which include charging infrastructure programs. Their collective programs exceed direct private investments and even government incentive programs.
- Numerous states have directed utilities to use ratepayer dollars to invest in EV charging infrastructure. Many states have justified this directive based on evidence that shows returns from EV customers over time to utilities exceed utilities' initial infrastructure capital costs. Those additional EV revenues benefit all utility customers in the form of lower overall electricity rates.
- The legal settlement related to the Volkswagen diesel scandal has also been one of the largest sources of investments, with a significant portion directed to the establishment of a VW subsidiary called Electrify America with requirements to fund and establish a national network of charging infrastructure.[30]

- State and regional regulatory programs have also been a source of funding:
    - Low carbon fuel standards: a greenhouse gas emissions program that provides credits for the use of electricity as a clean transportation fuel, which can be monetized by charging companies and fleets.
    - Carbon pricing mechanisms: in California, a cap-and-trade program has put a cap on economy-wide emissions. The proceeds from the sale of pollution permits are reinvested into clean energy, including electric vehicles and charging infrastructure. A similar program was adopted by the Northeast and Mid-Atlantic States (Regional Greenhouse Gas Initiative, RGGI).
- Private investments
    - Tesla has had a unique strategy of building the largest, national network of direct current (DC) fast chargers for Tesla owners – at a loss – as part of their competitive strategy to increase vehicle sales.
    - Other automakers are partnering with charging service providers to expand the charging network and improve the convenience of charging.
    - Most of the public infrastructure outside of Tesla's network has been funded through site-hosts, automakers, venture capital, and government/utility programs.

Vehicle Charging Technologies

China

- Adoption of a standard for charging infrastructure by China is intended to enhance the user experience, accelerate EV adoption, and improve charger utilization.
- Various hardware for charging infrastructure was utilized on both the vehicle and charging port side, which leads to interoperability challenges.

United States

- Three main types of EV charging in the U.S. (Level 1, level 2, DC) and most residential charging stations are Level 1 or Level 2.
- Unfortunately, there is no universal connector for DC fast charging, with European, U.S., and some Asian vehicle manufacturers utilizing the combined charging system (CCS) standard, Japanese automakers utilizing CHAdeMo, and Tesla using its own proprietary charging standard.
- Tesla offers the option for their customers to purchase additional charging adaptors that allow its vehicles to also connect to other ports.

Barriers and Challenges for EV Charging Infrastructure

- With an absence of favorable government policies, both public charging site hosts and charging service providers face a difficult business case to install infrastructure.
- There are common obstacles in both China and the U.S. (largely facing drivers who do not have access to home charging).
- Business and policy challenges include slow and expensive permitting and high capital costs, which can also determine the expansion and implementation of new charging stations, in particular DC fast charging stations.
- Overall there is low demand and willingness to pay for EV charging (largely from drivers who have access to home charging). Consumer experience challenges are prominent, such as lack of standardization, interoperability issues, and equipment failures.

Strategies to Increasing Investments and Improving the Economics of Charging Infrastructure

- To unleash utility investments, it is critical that state and national policy provide direction for utilities to invest in EV programs, including charging infrastructure. Utilities are increasingly seeing the benefits to their bottom-lines and their customers through increasing electricity sales and increasing the efficiency of the electrical grid through vehicle-grid integration. EV integration can also allow more renewable energy into the grid, which helps utilities meet renewable purchase targets and generates nonmonetary benefits such as energy security and environmental and social benefits.
- Recently, public utilities in California have reconsidered the design of demand charges – a monthly fee to commercial and industrial users based on the highest amount of power drawn. These demand charges can be cost-prohibitive for projects with many DC fast chargers. It is estimated that design changes and caps could reduce electricity bills by 30-50% for some public bus and commercial truck fleets as well as site hosts of DC fast charging stations.[31]
- For charging infrastructure service providers, strategies to improve the economics include increasing revenue, decreasing capital costs and operating costs, achieving higher utilization, capturing other revenue streams via advertising or site-host network fees, and increasing regulatory certainty. Many of these variables are affected by both utility programs and government policies.
- A coalition of organizations – including environmental organizations, consumer groups, organized labor, charging infrastructure providers, and automakers – are promoting a change to utility business models where utilities, as a normal course of business, cover the installation and costs of “make-ready” infrastructure involving the distribution system upgrade, wiring, trenching, conduits, and upgrades on the utility side of the meter up to a maximum cap level. The changes will allow customers to focus on simply the wiring from the meter to the infrastructure site, the costs of the electric vehicles supply equipment (EVSE), and the installation. One estimate is that this could reduce the costs of the charging infrastructure projects by an average of 40% in one utility territory.[32]
- Government agencies can play a critical role in supporting broader EV adoption by establishing EV infrastructure incentive programs. These programs can work to decrease capital costs, provide low-interest loans to charging service providers, require vehicle manufacturers to offer EVs for sale, and establish EV-ready building codes.
- Government agencies also play a critical role in facilitating coordination among various actors – including state and local government – as well as in providing public education and outreach.

I. By the Numbers: Charging Infrastructure Deployment

India Highlights

With a nascent electric mobility market, private and publicly owned companies ("public companies") have set up most of the charging stations, with limited government involvement in India. While 246,000 EVs were sold in FY2020 in India, only 1,332 charging stations were installed across the country, according to the DataLabs secondary research.[33] In India, two and three-wheelers sales accounted for 98% of the total EV sales (152,000 and 90,000 units respectively), unlike China and the U.S. where four-wheelers sales are predominantly higher.[34]

The Government of India's Phase-II of the Faster Adoption and Manufacturing of Electric and Hybrid Vehicles scheme (FAME II) created major growth opportunities for electric vehicles and charging infrastructure deployment in India. Released by the Department of Heavy Industry in March 2018, the scheme provides capital incentives for the purchase of EVs – focused on commercial and public fleets – and chargers.

Under the FAME India scheme, the number of charging stations is anticipated to grow in 2020, despite the economic downturn. In early 2020, the Indian government approved the set-up of 2,636 charging stations in 62 cities across 24 states and union territories. FAME II focuses on installing charging stations in cities with more than a million residents, smart cities, or major state capitals where utilization is likely to be higher.

In India, there are four main categories of stakeholders that have been the most active in advancing charging infrastructure:

- **Government (national and state)** – The government provides policy support, fiscal and non-fiscal incentives, and mitigates risks to advance the deployment of chargers. The Bureau of Energy Efficiency (BEE) is the nodal agency for charging infrastructure in India. State nodal agencies lead the work on setting up chargers in each jurisdiction.

- **Charging infrastructure equipment manufacturers** – Private companies are taking the lead in manufacturing charging equipment required by the Indian market. Some of the major businesses are Delta, Exicom, and Magenta Power.

- **Charging infrastructure service providers** – Private entities, public companies, and utilities are acting as charging service providers. While private companies like Fortum, Ola, and Lithium have set up chargers in limited geographies, public companies, like EESL, have taken a nationwide approach to reach most major cities. Oil giants like HPCL and BPCL have also entered the market.

- **Electric utility distribution companies** – Both public and private utilities provide a connection to the grid and supply power for charging EVs.

Key Takeaways

China

- China currently has the world's largest EV charging infrastructure network.[35]
- State-owned utilities play a critical role in initially establishing the majority of public charging infrastructure in China. But in recent years, private companies have also become major investors and account for a greater share of new installations. However, state-owned utilities, in some cases, are providing financing for companies that implement charging infrastructure.
- Nearly 40% of chargers are public, with the remaining 60% for private use.[36]
- Most public ports are not evenly distributed across China and are highly concentrated in a few of the largest cities, which also tend to have more robust EV programs and larger vehicle markets in China.[37]
- China's vehicle-to-charging port ratio has improved such that on average, for every 3.5 electric vehicles, there is now one charger (including public and apartment complexes) with some jurisdictions approaching a one to one vehicle-to-charger ratio.[38]
- The vehicle-to-charger ratio is significantly lower in China than in the U.S., mainly because of the greater proportion of Chinese residents in apartment complexes and needing public and apartment complex chargers.

United States

- California currently has the most developed EV market in the U.S.[39]
- In the U.S., most of the initial EV owners live in detached, single-family households with a garage, and most EV drivers in the U.S. are charging at home, followed by workplaces, and public charging stations.[40]
- Public charging in the U.S. has recently increased rapidly to reduce "range anxiety" among EV drivers and to expand the ability to utilize EVs for long-range trips. [41]
- The appropriate or ideal ratio of public chargers to EVs is somewhat uncertain, with some studies suggesting that a 3:1 or 10:1 EV to charger ratio (i.e. public, workplace, and apartment complexes chargers) may be appropriate.[42]

Discussion

China

China currently has the world's largest EV charging infrastructure network. As of October 2019, there were a total of 1,144,000 charging ports (also known as "charging piles" in China).[43] Of these:

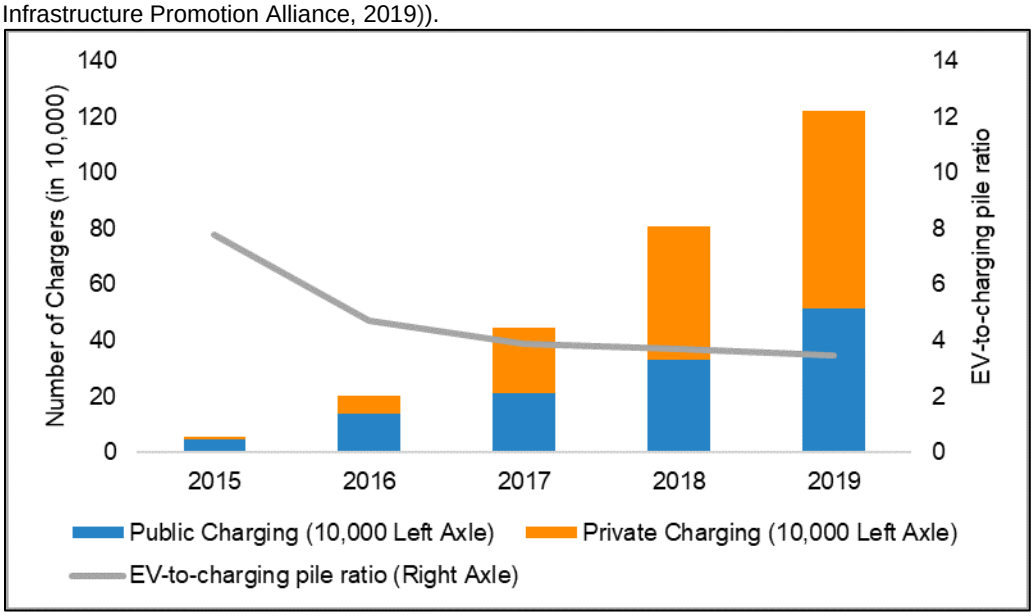
- 666,000 (or 58%) were private charging ports including at residential homes, apartment complexes, and companies.
- 478,000 (or 42%) were public charging ports.

In order to support inter-city travel of EV users, State Grid Corporation of China, the country's largest state-owned electric utility, has built a fast charging network that provides infrastructure coverage over numerous highway corridors – the slogan states there are now coverage of "ten south-north highways, ten east-west highways and two ring highways." By the end of 2019, China had more than 2000 charging service stations on highways in total, increasing the travel range of EVs. The number of charging service stations implemented over the last five years is depicted in figure 2. More detail on charging station development is discussed later in *Section*

III: Funding Sources for Charging Infrastructure, in short, the state-owned utilities played a critical role in establishing the initial charging infrastructure in China with private companies more recently accounting for most new installations.

Ten provinces and cities, including Beijing, Shanghai, and Guangdong, own more than 75% of total public charging infrastructure. In other words, of the over 600 cities in China, there is a significantly higher concentration of private charging piles compared to public piles in first-tier provinces and municipalities that represent the largest and often the most affluent areas.[44] These larger, or "Tier 1," cities provide stronger support for the construction of private charging ports and have focused on advancing cooperative models for apartment complexes that bring together property managers, EV owners, and private charging infrastructure providers.[45]

Figure 2: China National Charging Pile Development (Source: China Electric Vehicle Charging Infrastructure Promotion Alliance, 2019)).



China's vehicle-to-charging port ratio continued to improve, hitting 3.5 EVs for every 1 charger (public and private) by end of 2019 as shown in Figure 2. If only public charging ports are included, the ratio would be 8.3 EVs for every 1 public charger. As noted above, Beijing's and Shanghai's vehicle-to-charging port ratio is higher and hit 1.5 to 1 and 1.1 to 1 (public and private), respectively.[46]

The vehicle-to-charger ratio is much lower in China than in the U.S. because a higher proportion of residents in China live in apartment complexes (e.g. apartments, condos/flats) and therefore use communal chargers. In the U.S., most EV owners live in single-family homes and have access to their own private chargers.[47] The level of urban development and the type of housing helps to determine the right mix of EV charging infrastructure needed within a city.

United States

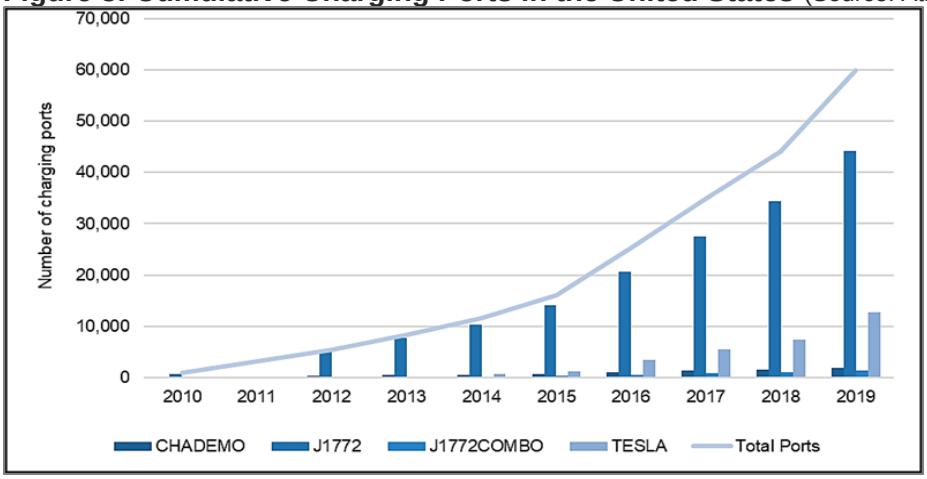
As of November 2019, there were over 75,000 public and private station charging ports at over 26,000 total locations in the United States.[48] The total number of private stations, public stations, and residential charging ports include:

- Over 64,000 Level 2 charging ports at over 23,000 locations, including public and private stations (e.g. government locations, campuses, office buildings, private fleet stations). Level 2 ports typically operate at about 6 kilowatts (kW), but depending on the equipment, this can vary from 2.5 up to 19.2 kW.[49]
- Over 11,000 DC fast charging ports at over 3,300 locations. DC fast chargers typically can charge at 50 kW, although the range can vary from 20 kW to 400 kW.[50]
- According to the U.S. Department of Energy, EV drivers do more than 80% of their charging at home.[51]While it is difficult to estimate the number of privately-owned, residential charging ports, it can be noted that, currently, most of the more than 1 million EVs on the road have access to home charging.[52]

Public charging in the United States has grown rapidly in recent years in anticipation of the arrival of longer range all-electric vehicles. The growth in the number of charging stations over the last decade is depicted in figure 3. Between the first quarters of 2018 and 2019, public charging grew by nearly 40 %.[53] For DC public fast charging, over 680 sites are for Tesla vehicles, over 2,200 sites support the CHAdeMO standard, and over 2,000 sites support the Society of Automotive Engineers (SAE) Combo standard.[54]

California has the most developed EV market in the United States with a ratio of approximately one charging port for every 23 EVs, which includes non-residential chargers (i.e. DC fast chargers that are public or privately owned; Level 2 public, workplace, and apartment complex chargers) as well as fully electric vehicles and plug-in hybrids.[55] Projections regarding what this ratio will need to be in order to meet anticipated EV adoption are uncertain, with a recent presentation by a utility organization showing potentially anywhere from a 3:1 to a 10:1 vehicle to non-residential charger may be appropriate (i.e., including public, workplace, and apartment complexes).[56] Research by the International Council of Clean Transportation (ICCT) states that, as EV adoption increases, the ratio of EVs to charging ports will likely also increase, as stations see higher utilization.[57]

Figure 3: Cumulative Charging Ports in the United States (Source: Atlas Public Policy, 2019)



This chart does not include privately-owned charging stations at residences, workplaces, etc.[58]

Roles of Key Players in Advancing Charging Infrastructure

Multiple types of government and business entities can carry out the various roles necessary to advance charging infrastructure. Across jurisdictions, some key roles include charging station site hosts, electricity generators, electrical grid managers, EV charging service providers, charging station equipment manufacturers, EV owners, and auto manufacturers. Figure 4 outlines these key roles and lists the actors that can fulfill them, with some U.S. entities shown as an example.[59] As discussed in Section III, financing for public charging installations has come from several actors, including government agencies, utilities, site hosts, and automakers.

Figure 4: United States Key Actors in Public EV Charging (Source: Center for Climate and Energy Solutions (c2es), 2015)

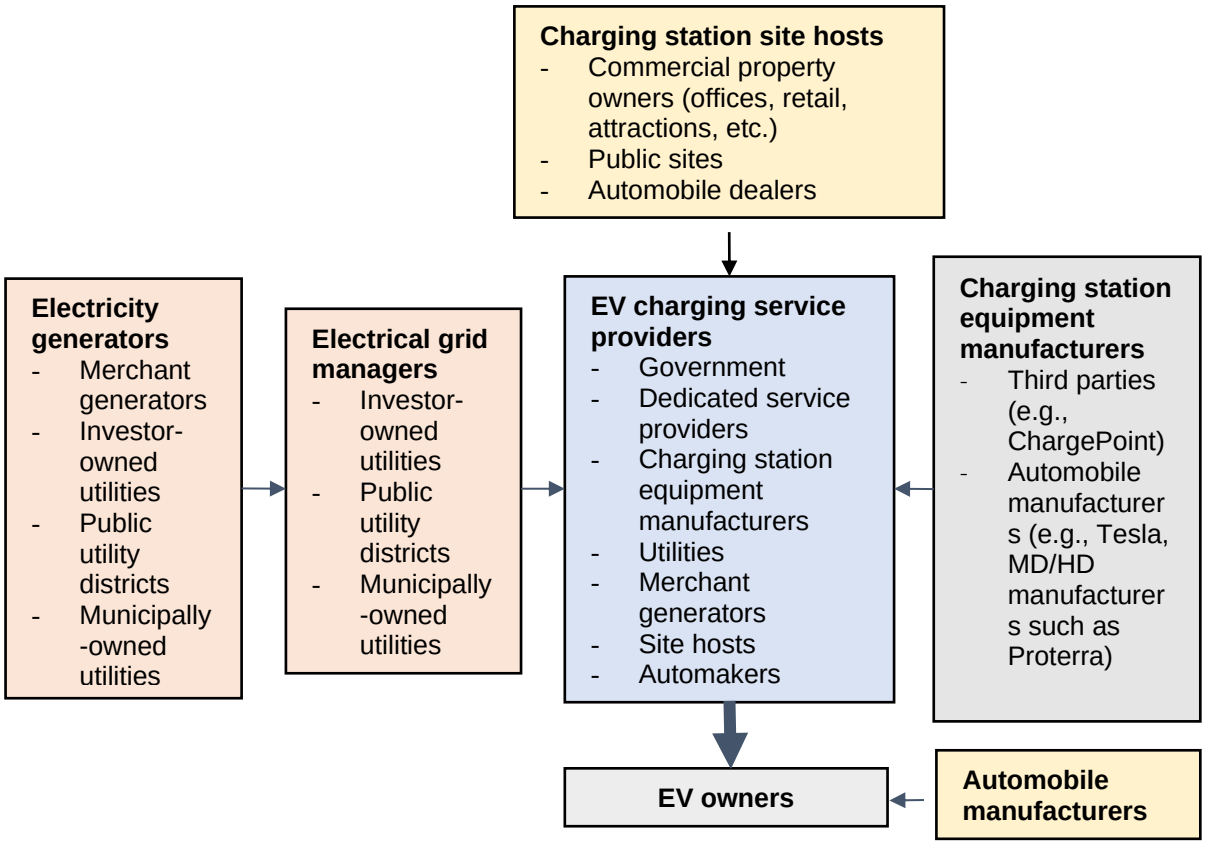


Figure 4 outlines the key roles in expanding EV charging infrastructure and lists the various players that can fulfill these roles.[60]

II: Gaps in Public and Private Charging Needs

India Highlights

More than 80% of the vehicles in India are two-wheelers. Initially, the market preference was for electric two-wheelers with removable batteries and home charging. The market is shifting with newer electric two-wheelers that do not have a removable battery and need access to public or workplace charging in addition to home charging.

- *EV-ready infrastructure*: Most people in Indian cities live in building complexes or apartment complexes, and therefore do not have a dedicated garage or parking space for a vehicle. Government officials and municipal leaders are now considering revising the building by-laws to ensure that all new buildings are EV-infrastructure ready. There are now some examples of several existing buildings where charging points are being installed to meet building code requirements. Going forward, India may need to consider similar cooperative solutions, as China is finding, to facilitate the necessary coordination between property owners of multi-dwelling units, EV owners, and infrastructure providers.
- *Consolidated information on charging infrastructure*: Several charging station service providers are now operating in India and installing chargers in different parts of the country.
- *Economics for public chargers*: The number of public charging stations needs to increase considerably to meet the government's EV deployment targets, but the economics for a private company to do so are weak. As a result, few taxi fleets, such as BluSmart, EEE taxi, and Ola, are moving forward with plans to convert to EVs.
- In discussions with stakeholders, numerous parties have supported the concept of having a mobile application or central database for charging stations by geography in India. The Ministry of Power has designated the Central Electricity Authority with the responsibility of developing and maintaining this central database to consolidate the location, availability, and technical specifications of all public charging stations.[61] This would help reduce range anxiety for drivers and improve the utilization of the chargers.
- To improve the economic case, some leading utilities and charging service providers are implementing innovative solutions, such as integrating charging points within lighting poles. The success of these pilots and their replicability as a model is under consideration.

Source: Ramesh Lalwani, Flickr

Key Takeaways

China

- Currently, the majority of EVs that have been sold are owned by consumers with access to their own private (home) charging in China.
- Additional charging infrastructure at apartment complexes and public charging stations is needed to reach a large part of the EV market who cannot charge at home and to enable widespread transportation electrification.
- Policies are being enacted to help overcome obstacles and barriers at apartment complexes, including cooperative models between property owners, residents, and infrastructure providers.
- Public charging infrastructure is increasing but the current utilization rate is low, suggesting that the siting of this infrastructure is sub-optimal.
- Consolidation within the charging infrastructure industry is occurring as smaller-sized companies are either merging or exiting the market. Together with shared platforms or apps, this consolidation may improve the economics and customers' experience.
- Ride-hailing services present a large opportunity for broader EV market adoption.

United States

- The majority of EV charging sites are residential since home charging is more straightforward in the U.S.
- To expand the EV market, states and cities are adopting policies to expand public charging access, workplace charging, and private access in apartment complexes.
- Key public charging locations include retail sites, curbside locations, and highway corridors in the U.S.
- Highway corridors are important sites for charging stations, particularly DC fast charging stations, to allow EV drivers to make longer trips and to relieve range anxiety (fear that a vehicle has insufficient range to reach its destination).
- Curbside charging locations are becoming increasingly important in urban settings where private and public parking is limited, and to provide charging for drivers who live in apartment complexes without charging access.
- Government-owned fleets may also benefit economically from vehicle electrification and infrastructure due to lower ownership costs of EVs.
- Electrification for ride-hailing and taxis may be particularly cost-effective given the potential for larger savings on fuel costs. Lyft, the second-largest ride-hailing company, based in the U.S., recently announced their plans to electrify their platform by 2030.[62]

Discussion

China

In China, apartment complexes are the predominant form of housing compared to the U.S., were detached, single-family homes with dedicated garages or driveways are the most common. Charging infrastructure at apartment complexes and public charging stations are thus particularly critical in China in the near term to enabling widespread transportation electrification.

According to the Chinese Electric Vehicle Charging Infrastructure Promotion Agency (EVCIPA), as of October 2019, among the 990,000 passengers, EVs sold by their automaker members, 67% or 666,000 of the EVs sold are owned by consumers with are access to their own private (home) charging. The reasons why the remaining 33% or 324,000 vehicles do not have home charging facilities include the following: the vehicle is part of a large company fleet with their own charging facilities (16.6%), there is a lack of available parking spots at the drivers' homes (3.2%), property management offices are not cooperating to install EV charging (3.2%), and there is difficulty with access to power (0.6%).[63]

With a large percentage of EV customers unable to access home charging, it is important to improve the availability of workplace and public charging facilities. China's public charging infrastructure has been steadily increasing over the past years, as shown in Figure 5. However, the utilization rate of public charging in China remains low and is estimated to average 10%.[64]

Figure 5: Monthly Increase of Public Charging Port/Piles in China (Source: China Electric Vehicle Charging Infrastructure Promotion Alliance, 2019)

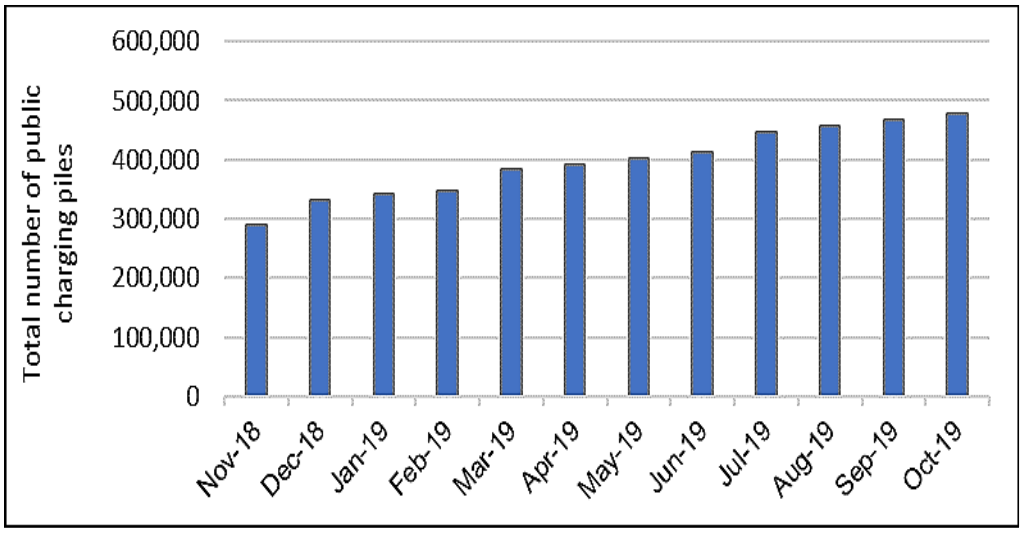


Figure 5 depicts vehicle charging infrastructure.[65]

Apartment complexes: Property management offices at apartment complexes are often reluctant to cooperate when residents want to install a charging port due to numerous barriers. Some of these barriers include logistical challenges in coordinating with multiple parties, the allocation of limited power supply capacity within the complex, installation costs, challenges with the creation of dedicated parking spots for EVs, the assignment of rights, and perceived safety concerns with electricity use.[66]

To help overcome these barriers, key provincial and municipal authorities are providing stronger support for private charging pile construction and have focused more fully on advancing cooperative models among property managers, EV owners, and third-party infrastructure companies. Some of the policies being enacted include:

- When a local authority conducts a performance evaluation of property management companies, the number of charging ports installed is one of the key evaluation indicators.
- Revenue sharing among infrastructure operators and property management companies.
- Encouraging sharing of private charging ports, where an owner will share with the local

community (e.g. an office building with private charging stations sharing with members from surrounding apartment complexes).

- Revision of building codes to ensure all new buildings have a minimum number of EV ready charging spots with the necessary conduit, capacity, and pre-wiring.

Charging Station Providers: As of October 2019, the top 8 charging service providers with more than 10,000 charging piles have 90% of public charging piles. While there is no accurate data on how many charging service providers exist throughout China, it is assumed that there are more than 1,000 throughout the country, if very small companies with just a couple of charging stations are included. China has been in the process of market optimization and consolidation. Due to the fierce competition in the market between charging service providers, it is expected that smaller-sized companies may gradually exit the market or merge with larger companies. Providers have also joined shared platforms, such as Xiaoju Charge – a subsidiary of ride-hailing company Didi – that are providing customers with a one-stop resource to identify and pay for charging stations. However, even the shared platforms are becoming competitive as shown in 2019 when three major charging service providers - TGOOD, Star Charge and iCharge – left Xiaoju Charge to create a similar platform to Xiaoju Charge.[67]

As noted below in *Section III Funding Sources for Charging Infrastructure,* the charging infrastructure industry used to be a monopoly by the State Grid (utility in China) until 2014 when it was open to private investments. In December 2018, major players in the charging service industry, including State Grid EV service company, set up a joint venture to establish a sort of "all-connected charging network".

Figure 6: Top Public Charging Service Providers in China (Source: China Electric Vehicle Charging Infrastructure Promotion Alliance, 2019)

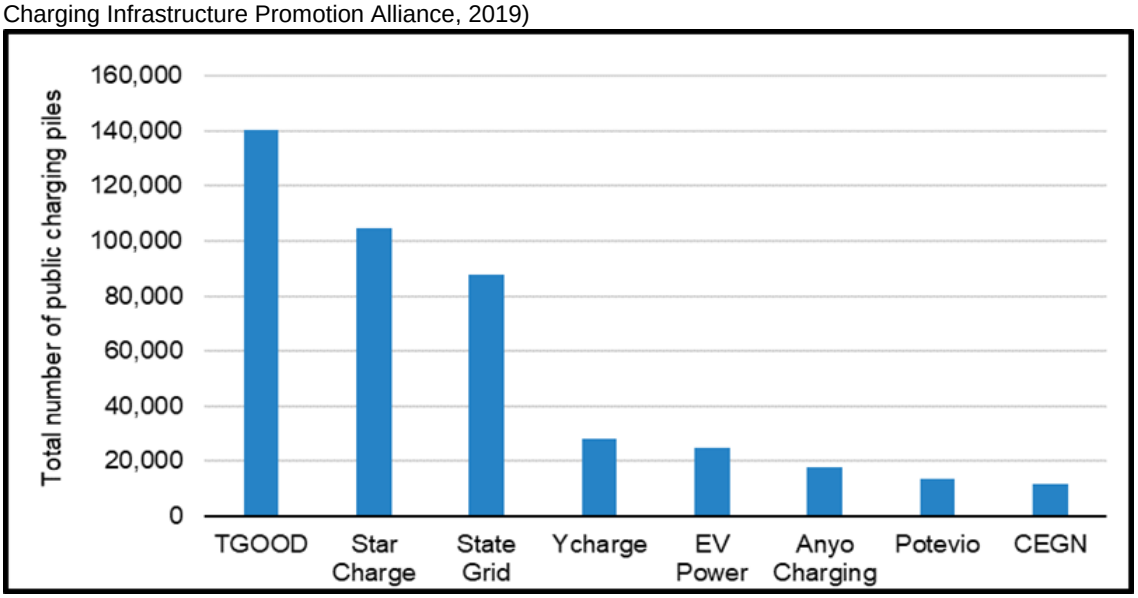


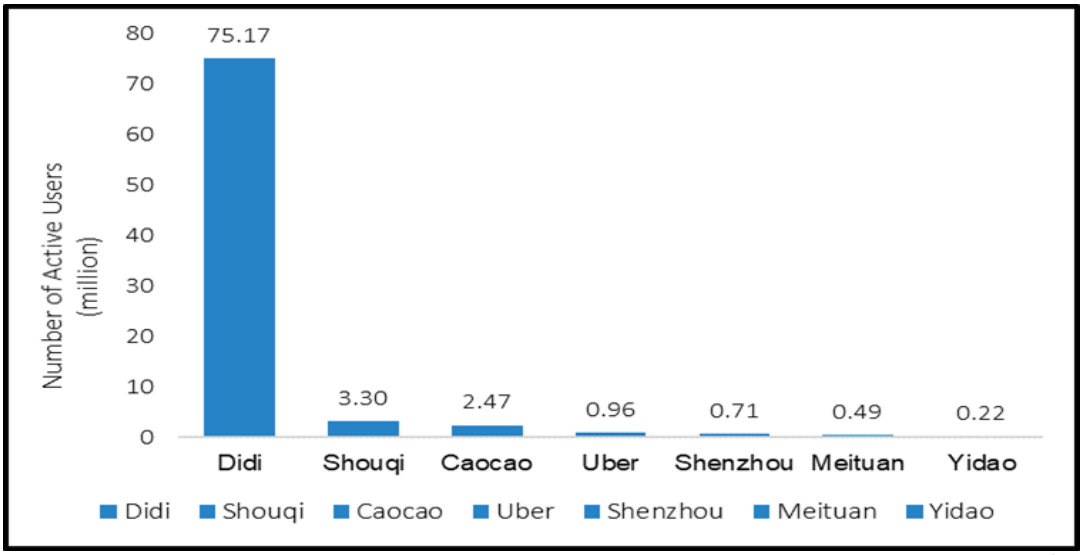
Figure 6 represents the number of charging stations the top 8 providers have in China.[68]

Ride-hailing and taxi fleets: The ride-hailing service industry has grown into a massive market in China. As of May 2019, the total number of active users of the 7 major ride-hailing service providers exceeded 88 million, with revenue in 2018 exceeding $44 billion (see Figure 7).[69] Caocao, which is the third-largest ride-hailing service in China and is backed by Zhejiang Geely Holding Group, is one of China's first ride-hailing service providers to offer EV car-sharing

services with an estimated 16,000 Vs across 25 cities. EvCard, an electric vehicle rental company owned by SAIC Motor Corp, claims it has 27,000 EVs in use across 62 cities.[70]

City governments in China also see the ride-hailing service industry as one of the target groups to promote EVs. Shenzhen required all newly added ride-hailing service vehicles to be pure battery EVs under the Interim Regulations on Ride-hailing and Taxi Service Industry Management, which was issued on November 11, 2019.[71]

Figure 7: Number of Active Users of Ride-Haling Services as of May 2019 (Source: Analysys News Service, 2019)



This graphic depicts the distribution of active ride-hailing service users in China.[72]

United States

Over 90% of EV charging sites across major U.S. markets are residential, and this remains true through 2025 and the foreseeable future, according to a recent ICCT report.[73] Since over 70% of households are single-family dwellings with most being owner-occupied, home charging is straightforward in the U.S..[74] For apartment complexes, drivers may not have access to charging at their building and could require access to public and/or workplace charging. By increasing charging infrastructure at apartment complexes, ICCT estimates that the amount of public and workplace charging needed could decrease by as much as eight percent in 2025.[75]

While most EV owners have access to home charging, greater availability of workplace and public charging stations will be essential to serve an increasing number of EV drivers without home charging access. Increased access will encourage drivers to use their EVs as they would a typical gasoline-based, or petrol, vehicle.[76] Charging infrastructure needs will also depend on the types of EVs in the population. For example, one analysis by the California Electric Transportation Coalition estimates that while a plug-in hybrid electric vehicle (e.g., Chevrolet Volt) would not require any DC fast chargers, rideshare vehicles (e.g., Uber EV) might require 10-20 times the number of DC fast chargers per vehicle compared to a non-rideshare, battery electric vehicle. The analysis estimated that California would need a ratio vehicle-charging port (non-residential) ratio of between 3:1 and 10:1.[77]

Similarly, ICCT estimates there were only about 25% of the workplace and public charging stations in 2017 required to meet 2025 EV adoption projections consistent with automaker,

policy, and underlying market trends across the top 100 U.S. metropolitan regions. The report concludes to meet 2025 projections, annual charging infrastructure growth rates will need to be 28% for workplace charging, 16% for public Level 2 charging, and 15% for DC fast charging.[78] Key public charging locations include retail sites, curbside locations, and highway corridors. Each of these locations is described further below.

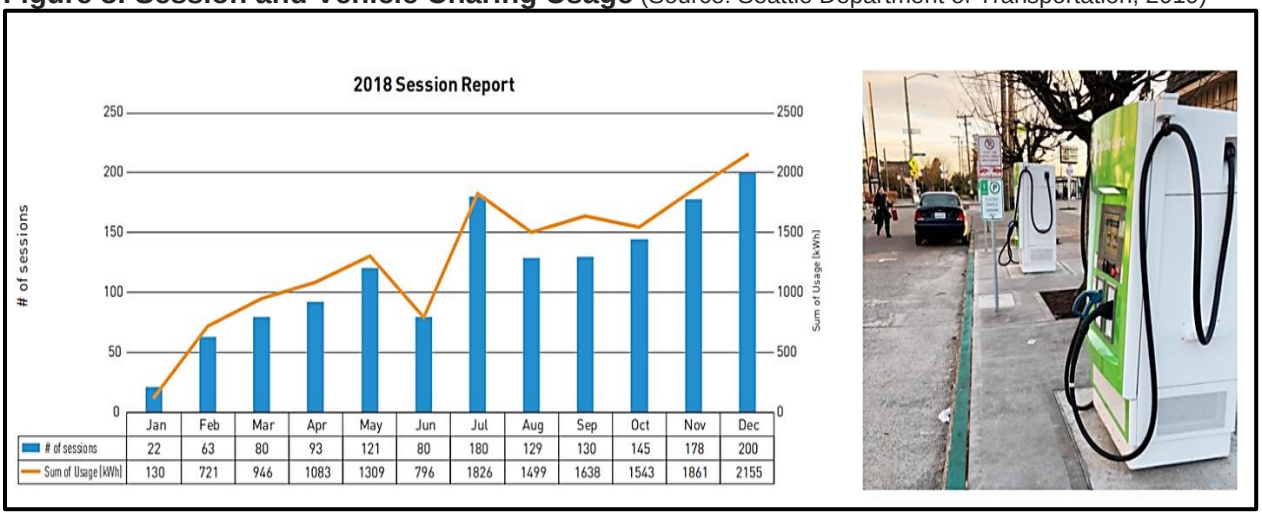
Retail sites: Charging infrastructure at retail sites can attract EV drivers and result in increased sales for the retail host, creating indirect revenue that can help improve the economics of the charging station.[79] A recent study by Atlas Public Policy on charging stations in New York state found that additional retail revenue increased charging station profitability by over 100% in most cases.[80] Innovative business models can use this indirect value from increased retail sales to help improve profitability for charging station owner-operators, even if the owner-operator is not the retailer. For example, retailers may agree to share some of their increased annual retail revenue with the owner-operator, helping to improve the charging station's economics. Business models that capture indirect value are discussed further in the VI: Key Strategies to Increasing Investments and Improving the Economics of Charging infrastructure section of the report.[81]

Street parking: Curbside charging locations are essential to provide charging for drivers who live in apartment complexes where there is no charging access, and are particularly important in urban settings, where charging options are limited. Cities such as Seattle, New York City, and Sacramento have all implemented programs specifically targeting curbside charging deployment. These programs include the Seattle Department of Transportation's Electric Vehicle Right-of-Way (EVCROW) pilot, the New York City Department of Transportation's Curbside Level 2 Charging Project, and the City of Sacramento's Curbside High-Speed EV Charging Pilot.[82] (Text box on Seattle EVCROW Pilot)

The City of Seattle in the United States conducted a pilot program on curbside charging as part of the Drive Clean Seattle Implementation Strategy, which aims to help Seattle achieve carbon neutrality by 2050. Under the Electric Vehicle Charging in the Public Right-of-Way (EVCROW) Pilot Program, Seattle City Light installed two public DC fast Chargers at curbside. SDOT evaluated these stations' usage from July 2017 through December 2018 and published an evaluation report in 2019.

Preliminary evaluation data indicates that some EV drivers used ESCROW stations as their primary charging point and support the idea that curbside charging locations may serve as an important charging option for EV drivers who do not have access to at-home charging. EV charging stations saw an increase in usage during the evaluation period, suggesting that the stations were beneficial to EV drivers. The report also notes that 100% of surveyed applicants stated that they would be interested in applying for future permits. SDOT is currently using evaluation data from this pilot program to determine whether it will implement another EVCROW program and, if so, how it will design the program to replicate successes and address challenges encountered in the pilot.[83]

Figure 8: Session and Vehicle Charing Usage (Source: Seattle Department of Transportation, 2019)



Session count and energy usage from Seattle City Light's two Direct current fast chargers located on the 2500 block of 16th Avenue S near the Beacon Hill Light Rail station (pictured on the right).[84]

Highway corridors: Highway corridors are important sites for charging stations, particularly DC fast charging stations, to allow EV drivers to make longer trips and to relieve range anxiety.[85] In recognition of the importance of highway corridor fast charging, the state governments of Washington, Oregon, and California funded the West Coast Electric Highway in the United States, a network of DC fast charging stations located every 25 to 50 miles along major west coast roadways.[86] A similar agreement has also been reached between eight other states to create an Intermountain West EV Corridor that would allow for EV charging across major highways.[87]

Public fleets: Public agencies can also benefit from expanded access to charging infrastructure to support public fleet electrification. These vehicle fleets have the potential to benefit from electrification due to the lower fuel and maintenance costs of EVs. New York City found that the total cost of ownership over a nine-year period was about 20% lower for their electric Nissan Leaf and hybrid Toyota Prius vehicles compared to their gasoline-powered Ford Fusion vehicles.[88]

Additional urban and rural charging infrastructure will be critical to support the wide-scale adoption of EVs in the United States. The U.S Department of Energy has begun to map charging infrastructure needs based on travel patterns and EV ranges. This analysis is designed to inform public and private stakeholders so they can efficiently deploy future charging stations.[89]

Ride-hailing, car-sharing, and taxi services: Ride-hailing services provided by transportation network companies (e.g., Uber, Lyft, Didi), and taxi fleets are both attractive targets for electrification given the large fuel savings from driving on electricity compared to gasoline. Ride-hailing has added an estimated 5.7 billion annual vehicle miles in the U.S., making electrification of ride-hailing vehicles important to meet transportation emissions reduction goals.[90] The EV Shared Mobility project in the United States is actively working to improve the business case for the electrification of ride-hailing fleets through various strategies, such as prioritizing EV charging at shared mobility hubs in Seattle.[91] New York city is also working to implement agreements with charging infrastructure providers and mobility service providers. to deploy EVs

for exclusive use by TNC and other for-hire drivers. These agreements include complimentary charging infrastructure and one-year exclusive use by fleet clauses.[92]

Car-sharing rental services, such as Zipcar, Turo, and Getaround present opportunities to introduce electric vehicles for personal use, rideshare drivers, and delivery services. Companies pursuing autonomous, self-driving vehicles such as Waymo, GM owned cruise, Uber, and Tesla are considering utilizing electric vehicles largely due to lower operating costs for high-mileage autonomous vehicles. Based on discussions with some of these companies, a dedicated and/or centralized charging infrastructure may be necessary with a higher emphasis on DC fast charging.

Commercial Trucks: For the electrification of medium and heavy-duty commercial trucks (MD/HD), private fleet-owned charging deports will be important. Generally, fleet owners will make decisions based on the total cost of ownership (TCO). Fleet owners will consider the capital costs of the necessary charging infrastructure, associated energy costs, and demand charges. A study by ICF International, commissioned by NRDC and California Electric Transportation Coalition, found that minimizing utility demand-charges (additional fees that utilities charge commercial customers for access to a higher level of power) while ensuring the electrical grid is adequately maintained, is important in order to maintain an attractive TCO for fleet owners.[93]

The initial deployments of commercial electric trucks may focus on local delivery trucks, refuse trucks, and local/regional haul given the attractive TCO for these vehicle categories, which also tend to be centrally refueled.[94] In addition, analysis of TCOs for electric MD/HD vehicles by Atlas Public Policy reveals that private, fleet-owned “depot” charging stations are likely to be significantly more cost-effective than public charging.[95] Research conducted by the North American Council for Freight Efficiency (NACFE) also supports this finding and concludes that MD/HD EV charging will focus on private, fleet-owned “depot” or “return-to-base” charging.[96]

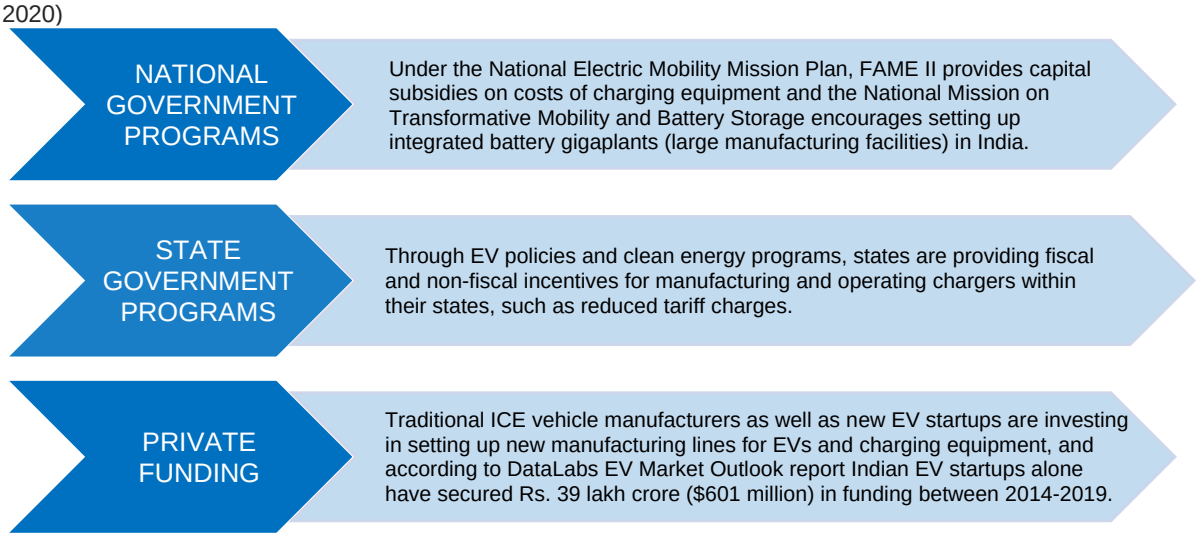
Source: Mohite Sameer, Flickr

III: Funding Sources for Charging Infrastructure

India Highlights

The two main sources of funding for initial EV charging infrastructure deployment are government and private investments. National and state government programs that have been adopted, or are currently proposed, provide incentives to set up manufacturing, subsidize the cost of chargers, and create other fiscal incentives (e.g. higher taxes on ICE vehicles). Private funding is focused on both indigenous manufacturing of EV chargers as well as installing charging stations in the country. Some private funding has also gone to incubating new indigenous EV charger manufacturing startups. In order to secure additional charging infrastructure funding in the future India should consider coupling utility-funded charging station investments with the country's grid modernization efforts.

Figure 9: Highlighted EV Charging Funding Sources for the Indian Market (Source: NRDC, 2020)



The figure above represents India's identified public and private funding sources.[97]

Key Takeaways

China

- Charging infrastructure development has been heavily supported by government investments, including through state-owned utilities together with national and local-level incentive programs and policies.[98]
- Governments and policymakers have increasingly opened the market to facilitate greater private investments in charging infrastructure, leading to growth in the number of charging infrastructure providers and overall investment levels.
- National directives have helped establish and promote the current charging infrastructure ecosystem. Programs, such as incentive funds for charging infrastructure, EV charging fee programs, and cooperative models between property managers at apartment complexes, have helped improve the operation of charging facilities.

- Many local governments have established complementary programs to the national directives. The local programs and incentives are based on different project factors, such as total investment, the power capacity of charging points, or fixed amounts.
- Utilities have made significant investments in charging infrastructure, largely aligned with national level directives. The utility investments have come from companies' social responsibility budgets or are made through a separate EV infrastructure entity. The utilities have built an intra-city network of charging stations to connect cities.
- Utilities are increasingly looking to invest in EV infrastructure as an attractive business opportunity. They have been among the first to install charging infrastructure and provide charging services and utilities have begun to make necessary grid upgrades to support charging infrastructure deployment.
- Automakers and energy companies are investing in acquisitions and joint ventures. Private investments are helping fill the gap in non-highway based public and private charging infrastructure.

United States

- In response to the global recession in 2009, the U.S. Congress passed the American Recovery and Reinvestment Act, which provided funding to vehicle electrification efforts, including an estimated 18,600 home, public, and commercial charging points.[99]
- Since then, federal and state governments – through various programs - have continued to be a large source of funding for charging infrastructure.
- Electric utilities are now becoming one of the largest investors through their EV-utility programs, many of which contain charging infrastructure programs. Their collective programs exceed direct private investments and even government incentive programs.
- Numerous states have directed utilities to use ratepayer dollars to invest in EV charging infrastructure. Many have justified this directive based on evidence showing the returns from EV customers overtime will exceed the costs to utilities for installing infrastructure.
- The legal settlement related to the Volkswagen diesel scandal has also been one of the largest sources of investments.
- State and regional regulatory programs have also been a source of funding:
    - Low carbon fuel standards: a greenhouse gas emissions program that provides credits for use of electricity as a clean transportation fuel that can be monetized.
    - Carbon pricing mechanisms: in California, a cap and trade program has put a price signal on carbon emissions with revenues reinvested into clean energy, including EV's and charging infrastructure. A similar program was adopted by the Northeast and Mid-Atlantic States (Regional Greenhouse Gas Initiative, RGGI).
- Private investments
    - Tesla has had unique strategy of building the largest, national network of DC fast chargers as part of their vehicle sales strategy – at a loss – in order to increase vehicle sales.
    - Charging infrastructure providers have installed the much of the public infrastructure outside of Tesla's network through financing from site-hosts, automakers, venture capital, government programs, and utility programs.

Discussion

China

Charging infrastructure development in China has been heavily driven and supported by national government targets, policies, and programs that provincial and local governments are responsible for implementing. In many cases, local governments will also augment national incentives with their own and have complementary programs.

National programs: Since 2014, both national and local governments have introduced various government incentive programs. At the national level, the Ministry of Finance and the National Development and Reform Commission allocated funds to local governments for the implementation of national charging infrastructure programs.

National policies cover charging facility planning, construction and operation, land acquisition, construction and operation incentives, power access and electricity prices, charging standards, interoperability, as well as charging service quality. Generally, provincial governments or local governments may establish the details related to the specific policies.

Table 1: Charging Infrastructure Policies in China (Source: NRDC and ChinaEV100, 2019)

Policy	Directives	Facility planning	Land	Construction & Operation Incentives	Power Access & Electricity Prices	Charging standards	Interoperability	Charging Service Quality
Notice on Relevant Issues in Policies on Electricity Prices for EVs	Electricity fees shall be paid at fixed prices depending on the site classification. Before 2020, EV charging and battery replacement service fees shall be in line with the indicative price administration of government.				x			
Guidance on Accelerating the Construction of EV Charging Infrastructure	By 2020, charging infrastructure system must meet the changing needs of over 5 million EVs	x						
Guidelines for Developing EV Charging Infrastructure (2015-2020)	By 2020, build more than 12,000 centralized EV charging and more than 4.8 million distributed charging piles	x				x		
Notice on Unveiling a New Energy Vehicle (NEV) Charging Infrastructure Incentive Policy and Strengthening Promotion	National incentive funds for charging infrastructure and construction over 2016-2020		x	x		x		

Policy	Directives	Facility planning	Land	Construction & Operation Incentives	Power Access & Electricity Prices	Charging standards	Interoperability	Charging Service Quality
and Application of NEVs during the 13th Five-Year Plan period. [100]								
Notice on Accelerating the Construction of EV Infrastructure in Residential Areas	Encourage and guide residential areas in constructing charging piles. Develop cooperative models between property managers and other parties, provide incentives for creative operating models like local centralized retrofitting, intelligent charging management, and multi-user time-sharing.	x	x	x				
Notice to Accelerate the Integrated Planning and Construction Process for Charging Infrastructure at Parking Lots	Accelerate charging facility construction in working units.	x	x	x				
Notice on Accelerating EV Charging Infrastructure in Working Units		x	x	x				
Action Plan on Promotion of NEV Charging Guarantee (2018-2020)	Improve the quality, technical and operating standards of charging facilities. Gradually allocate local financial purchase subsidies to support the construction and operation of charging infrastructure, the use and operation of EVs, etc.			x			x	x

This table categorizes the various EV policies and directives in China.[101]

Local government programs: The local incentive programs for charging infrastructure construction are in four categories:

- *Type 1: Incentives as a certain percentage of the total investment*
  - Beijing, Shanghai, Hainan, Wenzhou and Chengdu provide up to 30% of the construction investment.
  - Hangzhou provides up to 25% of the construction investment.
  - Guiyang provides up to 10% of the construction investment.
- *Type 2: Fixed amount incentive*
  - Jincheng in Shanxi province provides $430 for an AC charging pile and $860 for a fast charging station, and $142,800 for public bus charging and battery swapping stations

- *Type 3: Incentives based on the power capacity of charging ports/piles.*
  - Changzhou and Wuhan provide up to $60/kW for AC charging piles, and $85/kW for DC charging piles. Wuxi also provides the same amounts but caps the total incentive for a single charging station at $214,000.
  - Nanjing and Suqian provide the highest incentives of $85/kW for AC charging piles and $128/kW for DC charging piles, while Xiamen provides the lowest of $20/kW for AC charging piles and $70/kW for DC charging piles.
- *Type 4: Incentives on both investment in construction and operation*
  - *Shanghai (See below for more details)*

In addition to the incentives on the construction of charging infrastructure, officials are working to create a more attractive business case for the charging services industry. It is also important to create a level playing field for all charging technologies as enhancing consumer choice can help in accelerating EV adoption. In May 2016, Shanghai was the first city to issue a policy to provide incentives to improve the economics for charging and battery swapping stations. Charging infrastructure for public transportation, sanitation trucks, etc. are eligible for incentives, which are 0014 $/kW (charging) and 0.018 $/kW (battery swapping), with annual upper limits of 2,000 kW and 1,000 kW, respectively. In addition to Shanghai, other provinces and cities, including Hainan, Jiangxi and Nanjing, have introduced similar programs.

In October 2018, Beijing rolled out an incentive program based on routine and annual assessments of the public charging infrastructure in the city. The indicators of the assessment include the average charging price, utilization, maintenance management, and interoperability. The new policy incentivizes charging service providers to improve their operation through indicators that encourage efforts to reduce unexpected power cuts, malfunction, as well as incidents where internal combustion engine vehicles (ICEVs) are parked in parking spots with EV charging. It is expected that incentives based on the operational performance indicators will also gradually help optimize the siting of the charging infrastructure.

Utilities: The two state-owned utilities in China – State Grid and China Southern Power Grid - have made significant investments in charging infrastructure, primarily guided by the national government targets and policies. The utilities were among the first to install charging infrastructure and provide charging services. State Grid invested $4 billion (USD) between 2006 and 2018 to build more than 5000 charging and battery swapping stations and installed 56,000 charging piles, including a fast charging network across major highways. The two utilities have also invested in grid upgrades to the distribution network to meet charging needs. To date, State Grid has invested $940 million (USD) to ensure public charging infrastructure is connected to power.[102] Most of the investments, however, comes from the companies' social responsibility budget or are made through a separate EV infrastructure entity.[103]

The utilities also play an important role in financing, including holding a 69% share of Xiongan Lianxing Network Technology, which operates an estimated 80% of the charging stations in China. The remainder of the joint venture is financed through private companies Star Charge and TGOOD Electric Co, LTD (TELD).[104] The utility role will increase in coming years, as State Grid announced in April of 2020 it would be installing 78,000 additional charging stations with 18,000 of those earmarked for public use, while Southern Power Grid announced plans to build 150 large charging parks that will add an additional 380,000 charging points over four years.

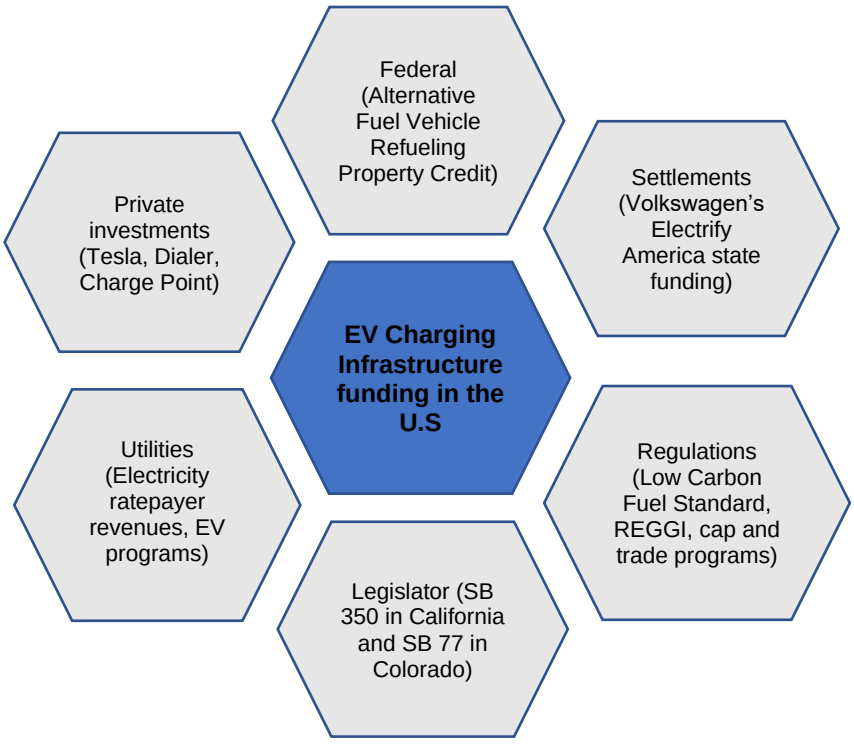
Private investments: Over the past five years, numerous private Chinese companies have filled the gap in non-highway based, public and private charging infrastructure with TGOOD, StarCharge and Ycharge among the largest (see Figure 6). Today, there are more than 1,000

charging service providers, including small operators, according to experts at the EV Charging Infrastructure Promotion Alliance (EVCIPA). Increasingly, multi-national automakers and energy companies are also investing through acquisitions or participating in joint ventures.[105]

United States

Historically, the federal and state government has been a large source of funding for public charging infrastructure. Electric utilities are becoming an increasingly significant source of funding.[106] Direct private investment by charging service providers and automakers, while essential for the long-term durability of the EV market, has played a relatively smaller role in charging infrastructure funding in the United States.[107] This was mainly due to the poor economics of running a public charging network with low utilization. When a healthy average use is achieved, the charging infrastructure can be operated profitably. A breakdown of both U.S. private and public funding and financial mechanisms is depicted in figure 10.

Figure 10: EV Financial Mechanisms (Source: NRDC, Atlas Public Policy, 2020)



Federal programs: At the federal level, the intermittently available Alternative Fuel Vehicle Refueling Property Credit has awarded $537 million in tax credits for charging infrastructure through the end of 2017 when it expired.[108] In the early days of the market, the American Recovery and Reinvestment Act (ARRA) of 2009 provided $400 million of funding to support vehicle electrification efforts.[109] ARRA funds supported the EV Project, which deployed over 12,000 Level 2 and over 100 DC fast charging stations, as well as a program called ChargePoint America, which deployed 4,647 residential and commercial charging stations in nine U.S. regions.[110]

State programs and VW settlement: 18 U.S. states have allocated a total of over $525 million in public funding for light-duty EV charging through October 2019 through various programs.[111]

In addition, the single largest public investment in EV charging in the U.S. has resulted from the legal settlement by the U.S. Environmental Protection Agency and the California Air Resources Board with Volkswagen (VW) resulting from the diesel emissions scandal. The settlement requires Volkswagen to establish a $2 billion National Zero Emission Vehicle (ZEV) Investment Plan targeting charging infrastructure and EV awareness, resulting in the creation of the company Electrify America.[112] In addition, the settlement established a $2.9 billion state-controlled Environmental Mitigation Trust to fund projects that reduce diesel emissions. States received funds proportional to the number of vehicles affected by the VW diesel scandal and can spend up to 15% on light-duty EV charging infrastructure. As of October 2019, 47 states have committed to invest $306 million in light-duty EV charging infrastructure with states already awarding $27 million.[113]

Utilities: Electric utilities are emerging as one of the largest actors in expanding the charging infrastructure network through their investments. In the United States, through May 2020, 45 utilities across 26 states have been approved to invest nearly $1.5 billion in EV charging-related programs. Another $1.3 billion in utility-EV programs have been proposed and are pending approval.[114] In certain cases, electric utilities may be permitted to use electricity ratepayer revenue to invest in charging infrastructure and distribution upgrades and to justify those investments based on nonmonetary values, such as environmental and social benefits. But even absent those indirect benefits, the direct revenues from EV customers can exceed the utility costs of serving the EV load and the costs of providing EV infrastructure programs.[115] Additional revenues can be automatically returned to all utility customers, which help drive down electricity rates. Among the many activities, utilities are engaging in to support transportation electrification via EV programs, some have directly owned charging equipment, funded a portion of the charging installation, conducted consumer education programs, and offered special electricity rates for EVs.

State legislatures and state utility commissions in the U.S. play an important role in facilitating utility investment in EV infrastructure by authorizing or requiring utility EV programs and investment. Notable examples of state legislation requiring utility investment in EV infrastructure include SB 350 in California and SB 77 in Colorado. California leads in utility investment in EV infrastructure with over $1 billion in approved programs. Colorado utilities have also emerged as leaders in utility investment, with over $4 million in EV-related investment filed for in 2019.[116]

Public utility commissions can also play an important role in utility investment in EV infrastructure by authorizing or requiring such investments. For example, in a February 2019 Order, the Minnesota Public Utilities Commission found that utilities must play a role in EV infrastructure investment.[117] Minnesota is among the top five states in terms of approved utility investment in EV infrastructure, with over $26 million of investment.[118]

Private investments: Companies including charging service providers and automakers also provide critical investment in charging infrastructure. Approximately $860 million of private investment in EV charging companies in the United States has been recorded, not including the $2 billion in VW settlement funds to form Electrify America. Much of these private investments have come from Daimler, BMW, Nissan, and Chevron. Charging service providers such as ChargePoint, EV Connect, and Volta Charging have also invested. Financing rounds for infrastructure companies are needed to help expand the charging network and improve the convenience of charging throughout the Unites States.[119]

Tesla had a unique strategy of building a large national network of 1200 DC fast charging stations with 9000 individual chargers for their owners, using their own charging standard, as part of their vehicle sales strategy rather than a e profitable stand-alone business. Some industry analysts have cited their “supercharger” network as a major reason for Tesla’s lead in EV sales globally and in the U.S., where it comprises roughly half of all EV sales.

Source: Electrek

Tesla has always stated the charging network portion of their business would never be profitable. In fact, up until 2017, Tesla gave free charging to new buyers but could no longer sustain that customer perk with the introduction of their lower-cost Model 3. Currently, it charges new Tesla purchasers around $0.28 per kilowatt-hour (kWh) to utilize their network and has also instituted idling fees to prevent owners from leaving their vehicles at superchargers. Tesla has always stated the charging network would never be profitable. Demand charges (fixed component of the electricity cost) are a large reason that can make public DCFC a difficult business, at least in the early days when charger utilization is low and EV penetration is low.

State clean fuel programs and cap-and-trade regulations: Fuel regulations also provide another important source of funding for electric vehicle charging infrastructure. For example, the California Low Carbon Fuel Standard (LCFS) and Oregon Clean Fuels Program provide credits for low-carbon transportation fuels, including electricity, based on their lifecycle reductions in greenhouse gas emissions relative to gasoline or diesel. Under this program, charging service providers receive emission reduction credits for the low-carbon electricity provided relative to petroleum-based gasoline, as well as credits for installing public DC fast charging which can be sold to fuel providers who must reduce their carbon footprint. Similarly, revenues from the Regional Greenhouse Gas Initiative cap and trade program operated in the Northeast can be used for EV infrastructure investment.[120] In addition, twelve Northeast and Mid-Atlantic states are currently developing a cap and trade program to include transportation fuels, with proceeds eligible to be invested in clean transportation initiatives.[121]

IV: Vehicle Charging Technologies

India Highlights

Currently, India has not standardized requirements around private or public charging infrastructure and instead allowed numerous charging connector standards to be utilized by automakers depending on their preference. This means that charging stations may provide one, some, or all connector options (Bharat charger AC001, DC001, CHAdeMO, CCS and GB/T) to EV users on a common board or kiosk. The specifications for both chargers and fast chargers are outlined in table 2.

Ultimately, the lack of standardization will lead to interoperability challenges, reduced access by the public, and decreased utilization of charging infrastructure. China, also facing initial interoperability challenges has now adopted national standards for charging infrastructure. While the U.S. has not standardized the charging connector, California may consider requiring standardization in future rulemakings for vehicles.

Source: Paul Sladen, Creative Commons

Table 2: Specifications for Charging Stations in India (Source: Government of India Ministry of Power, 2020)

Fast chargers	Slow/moderate chargers
• CCS (min 50 kW) • CHAdeMO (min 50 kW) • Type-2 AC (min 22 kW)	• Bharat DC-001 (min 15 kW) • Bharat AC-001 (min 10 kW)

The table above is a summary of the India charging infrastructure categorized by model types and load.[122]

Key Takeaways

China

- Various hardware for charging infrastructure was utilized on both the vehicle and charging port side, which leads to interoperability challenges.
- Adoption of a standard for charging infrastructure by China is intended to enhance the user experience, accelerate EV adoption and improve charger utilization.

United States

- Three main types of EV charging in the U.S. (Level 1, level 2, DC) and most residential charging stations are Level 1 or Level 2.
- Unfortunately, there is no universal connector for DC fast charging, with European, U.S., and some Asian vehicle manufacturers utilizing the CCS standard, Japanese automakers utilizing CHAdeMo, and Tesla using its own proprietary charging standard.
- Tesla offers their customers the option to purchase additional charging adaptors that allow its vehicles to also connect to other ports.

Discussion

China

Prior to 2015, various hardware for charging infrastructure was utilized on both the vehicle and charging port side, leading to interoperability challenges. To correct interoperability issues a new national standard for charging ports was established by the government such that there is one standard for Level 2 as well as one standard for DC fast charging (China Guóbiāo or GB/T), as opposed to the U.S. where multiple standards persist (see table 3). All new electric vehicles sold in China are required to utilize the GB/T standard.

Adoption of a standard for charging infrastructure by China is intended to enhance user experience, accelerate EV adoption, improve charger utilization and place China in a leadership position. By the end of 2018, approximately 60% of public charging piles met the 2015 national standard. The GB/T standard currently utilized in China can reach max power levels close to 240 kW. However, new GB/T standards are being developed that may allow up to 900 kW.[123]

United States

There are three main types of EV charging options in the United States, which vary in terms of voltage, power output (kilowatts), electrical requirements, connector standards, and, ultimately, how quickly they can charge an EV. Most residential charging stations are Level 1 or Level 2, while most public charging stations are Level 2 or direct current (DC) fast charging stations. In the United States, both the Level 1 and Level 2 use standards from the Society of Automotive Engineer (SAE) J1772 standard for connectors. Unfortunately, there is no universal connector for DC fast charging, and three standards are currently in use: SAE Combo (Combined Charging System) (Asian, European, and U.S. manufacturers), CHAdeMO (Japanese manufacturers), and Tesla connectors. Tesla offers charging adaptors that allow its vehicles to also connect to the other ports. The three main types of charging options and their key characteristics are summarized in Table 3 below.

It is noted however that recently, new fast charging networks in the U.S. – outside of Tesla's – are increasingly using the SAE Combo (CCS) standard as increasing U.S., European, and Korean manufacturers increase the number of their EV products. The Japanese Nissan Leaf remains the main product line-up to utilize the CHAdeMO standard.[124]

Table 3: Types of Chagrining Options in the United States (Source: Atlas Public Policy, 2019)

Low – AC 120V "AC" LEVEL 1	Medium – AC 240V "AC" LEVEL 2	High – DC Fast Charge
 J1772 charge port	 J1772 charge port	 J1772 Combo  CHAdeMO  Tesla combo
• Uses standard outlet (120 V AC) • Power requirements up to 1.4 kilowatts, like a toaster • Adapter comes with the car • Accommodates average daily driving needs • Low-cost installation, often free • Charging rate: 3-5 miles of range per hour	• Requires higher-voltage circuit (240 V AC) • Power requirements up to 19.2 kilowatts, like an electric clothes dryer • Equipment & installation costs vary widely (~$6,500 in public and ~$2,000 at home) • Charging rate: 12-75 miles of range per hour	• Requires very high voltage circuit & 3-phase power (200 - 450 V DC) • Power requirements up to 400 kilowatts, like the max power for several homes • No common connector standard (CHAdeMO, SAE Combo, Tesla) • Equipment & installation costs vary widely • Can approach gasoline refueling experience: 100 miles to over 300 miles of range per hour

This table lists the three main types of charging options in the U.S. and their key characteristics.[125]

There are no unique hardware requirements inherent to MD/HD charging; however, due to the high capacity of electric MD/HD vehicle battery systems, Level 2 and DC fast chargers are the practical charging levels for MD/HD fleet operators.[126] Some electric MD/HD manufacturers such as Siemens install charging equipment onboard the vehicle while other charging manufacturers such as ChargePoint with their Express Plus charging system include charging equipment in the external charging system.[127]Software requirements for MD/HD charging are particularly important, as electrification of MD/HD vehicles most often occurs in fleets. Software that allows multiple chargers at a site to communicate in order to optimize sequencing, manage load, and account for dynamic electricity rates is essential for cost-effective MD/HD fleet charging.[128] In fact, differences in charging software rather than hardware are what primarily distinguish MD/HD charging providers from one another.[129]

In addition to the lack of a single set of charging standards, there is a lack of communication protocols for equipment in the U.S. This poses a barrier to the potential capability of EVs to provide a myriad of services through vehicle-grid integration (VGI) solutions such as smart charging, congestion management, and to aid in grid resilience. For example, smart charging can lower the costs for EV drivers in regions that offer lower electricity tariffs for charging during off-peak times; helping utilities avoid brown-out situations through demand response services, and allow for increased integration of variable, renewable resources such as wind and solar at a lower cost.[130] Increasingly, many of the automakers have vehicle-based telemetry already

embedded that can be leveraged to provide VGI services. In addition, “smart” EVSE can also provide similar services or additional functionality.

Numerous efforts in both the U.S. and European Union have been initiated to investigate EVSE standards, frameworks and communication protocols to both accelerate EV adoption and futureproof current smart charging programs.[131] A few examples of key findings from these efforts include:

- In the Netherlands, every public charging station (and many private stations) can now be operated and paid for using a single radio-frequency identification card or key fob.
- A consensus of using Open Charge Point Protocol (OCPP) and Open Clearing House Protocol (OCHP) for all publicly accessible charging infrastructure has been found. Further EN 61851, ISO 15118 are highlighted as the preferred standard for EV to EVSE communication protocol to enable all use cases for VGI.[132]
- The need for a cloud-based marketplace has been identified to enable business-to-business (B2B) exchange of data for the interoperability of billing between providers. Research and implementation of these standards and such a marketplace are ongoing, with ElaadNLs’ OCPI (Open Charge Point Interface) being a frontrunner for international adoption in Europe.[133]

Source: Maurits van den Toorn, Flicker

V: Key Barriers and Challenges for EV Charging Infrastructure

India Highlights

In China and the U.S., to enable a more widespread public charging network to be created, the national government, local governments, and electric utilities have co-invested in charging infrastructure together with infrastructure providers and vehicle manufacturers.

In India, charging infrastructure service providers are struggling with numerous barriers and challenges, summarized in the below list. However, NRDC's analysis shows that with more ambitious and sustained policy interventions like those in China and in specific regions of the U.S., a more favorable investment climate for charging infrastructure can be created.[134]

- High initial setup cost – Cost of charging equipment, land cost, and grid connection cost (especially for fast chargers) are some of the high upfront costs that are to be borne by EV charging service providers. Though the cost of equipment is subsidized under FAME II scheme by the government, the subsidy is yet to be disbursed to the companies.
- Improving the economics for public chargers – Due to lower EVs deployed on the ground, the utilization of public chargers remains low. Under-utilized assets led to lower revenue which increases the payback period and reduces the profitability of the project
- Access to finance – Limited financing is available for purchasing or setting up charging stations in the country as banks and financial institutions are unaware of the risks and challenges posed by the sector.
- Low support from utilities – Utilities provide the fuel for driving electric vehicles. It has been observed in many cities that charging service providers are facing multiple challenges with respect to getting the electricity connection in time, availing the EV charging tariff and a separate metered connection for vehicle charging.
- Lack of consumer awareness – Consumer awareness, familiarity and experience of electric vehicles plays an important role in alleviating barriers like range anxiety and helps in increase sales of these vehicles. Due to very low vehicle deployment and limited experience with charging stations, consumer awareness about EVs remains low in India.

Source: Sasha India, Flickr

Key Takeaways

- Without favorable government policies, charging service providers face a difficult business case to install charging infrastructure.
- Business and policy challenges include slow and expensive permitting; high upfront costs can also be determinate for the expansion and implementation of new public charging stations, in particular, DC fast charging.
- Overall there is low demand and willingness to pay for EV charging (largely from drivers who have access to home charging).
- Consumer experience challenge with lack of standardization and interoperability issues and stations and equipment out of order.

Discussion

This section describes some key challenges facing the EV infrastructure market in the U.S. and China and describes ways policymakers and companies are working to overcome these obstacles. Creating a robust, ubiquitous network will require large, additional investments in charging infrastructure at apartment complexes, at workplaces, at businesses, and in public spaces. However, infrastructure providers face a "chicken-or-egg" dilemma of whether to make investments without certainty in EV deployment and charging infrastructure demand.

Some major challenges in both China and the United States include:

1. **The economics of public charging infrastructure:** Without favorable policies in place, infrastructure providers – whether private companies or publicly owned utilities - face a difficult business case. Barriers to installing and operating charging equipment can include high capital and operating costs, high electricity tariffs and demand charges, low demand and willingness to pay and thus potentially low revenues during the early EV deployment stage. In the U.S., stations can require extensive construction (trenching, wiring, paving), are often subject to requirements to serve the general public (e.g., Americans with Disabilities Act compliance), and generally must be designed to withstand significant wear and tear from weather. Public charging stations, in particular, DC fast charging stations face potential costs from electric-panel upgrades; host-site identification, analysis, and screening; negotiation, legal review, permitting, and lease execution; and electric utility interconnection fees.[135] DC fast charging stations have power ratings as high as 400 kilowatts, compared to around 20 kilowatts for Level 2 charging stations, they may face high operating costs due to demand charges, which are based on the station's peak demand. The combination of high demand charges and low utilization at DC fast charging stations makes it very difficult for these stations to recover costs and earn a profit. In fact, a recent study by the Great Plains Institute found that it was nearly impossible for DC fast charging stations with power ratings higher than 150 kilowatts to break even when demand charges were applied.[136]

   Some automakers, such as Tesla, utilize a "loss leader" model for their Supercharger network in order to attract new drivers while maintaining high customer satisfaction by reducing range anxiety. Other providers offset costs through monthly subscription fees on EV drivers, adding service fees for charging by the minute or by the kilowatt hour, putting up advertisement displays, charging site-host fees for network access and

functionalities, or having site-hosts see the value from having customers remaining at their business for a longer period while charging.

2. **Positive EV consumer experience**: In both countries, EV consumers face an often fragmented public EV charging system in comparison to gasoline stations that are largely widespread and standardized. Issues faced by EV consumers include challenges such as different membership cards and payment methods, limited access to stations or finding stations out-of-service, and lack of standardization and interoperability.[137]

3. **Low demand and willingness to pay***:* A robust and ubiquitous charging infrastructure network can generate new interest in EVs by reducing concerns and "range anxiety" among EV buyers. But actual demand for public charging can be low in regions where EV deployment is just starting or where convenient home charging is available. Research shows that Level 2 stations must be used more than once per day to achieve a return on investment. That number is higher for DC fast charging stations and, as discussed further below, depends on the kilowatt rating of the station and whether or not the station is subject to demand charges.[138]EV owners' low willingness to pay for public charging is largely due to the fact that many EV owners have access to inexpensive home charging. If charging station fees greatly exceed the residential, retail rate of electricity, drivers with access to home charging will be less likely to use public charging unless necessary. Currently, charging fees at DC fast charging stations far exceed retail electricity rates in the United States, which average less than 0.11 $/kwh and only get as high as about 26 cents per kilowatt-hour in the most expensive state of Hawaii.[139] Even Tesla superchargers, which offer some of the cheapest fast charging charge 0.28 $/kwh.[140] Other fast charging providers such and Blink charge as much as 0.69 $/kwh and many providers also charge session fees, time-based fees, or subscription fees.[141]

4. **Permitting***:* In both China and the U.S., charging infrastructure permitting can be time-consuming and costly. For jurisdictions without enough permit officers and inspectors, or without codes and standards and a process already in place for EV charging infrastructure, it can take weeks or even months to obtain approval for charging infrastructure. Some jurisdictions, like California, now have state processes in place to streamline permitting, although local implementation can still be slow.[142]

5. **Consumer Experience***:* At any given time, a portion of the charging network may need servicing due to a variety of factors including hardware malfunction, wear-and-tear, software malfunctions, vandalism, or even abandonment (when a company goes out of business). In some instances, where charging providers simply sell equipment to a business site, the business owner "host" may be responsible for maintenance or repair of stations. The host may not have a strong incentive to report and cover the costs of a repair until there are enough customer complaints.

6. **Charging at Apartment Complexes and Parking Lots**: *Section II: Gaps in Public and Private Charging Needs*, discusses the challenge of EV owners who are either renters or owners, and who do not own dedicated parking, must have willing property managers or owners to facilitate installation of charging infrastructure. In both China and the U.S., this has meant that parties are held captive to property manager decisions, absent specific local or state level policies.

VI: Key Strategies to Increasing Investments and Improving the Economics of Charging Infrastructure

India Highlights

Transitioning to electric mobility is at a nascent stage in India. The government has taken initial steps to strengthen the economics of charging infrastructure in the country including:

- Decreasing the upfront capital cost by proving subsidy on the cost of the charging equipment under the FAME II scheme. Some state-level electric vehicle policies also support the deployment of fast chargers by proving capital incentives or other benefits.
- Reducing the land cost through the initial deployment of charging stations in Government offices and buildings. The national government is also encouraging all state governments to include electric vehicles in the government vehicle fleet.
- More than fourteen states in India are reducing electricity cost through the introduction of a special lower electricity tariff for EV charging. Strategies like exemption of demand charges and introduction of time-of-day charges has been undertaken by a few states.
- Department of Heavy Industries is working on developing a common payment platform to increase the interoperability of charging stations across vendors and cities.
- To secure the supply chain, the government is encouraging indigenous manufacturing of electric vehicles, charging stations and batteries through subsidies and incentives under national and state-level programs.
- In India, the majority innovation in the electric mobility space is happening in the startup sector. Start-ups are coming up with innovative ideas and products that cater to the Indian market. For example, Ather Energy in Bengaluru has launch electric scooters with multiple ride modes to match the Indian road and traffic situation. In addition to vehicles, they have also set up a public charging grid at convenient points in the city. The electric scooter can be charged while parking at a public charging point or using a simple 5A socket.

Source: France in India, Flickr

- Some utilities like BSES Rajdhani Power Limited are going beyond the traditional solutions and planning to set up affordable public charge points on lighting poles to cater to vehicles parked on the streets. Many households do not have a dedicated parking spot, and such solutions can easily increase access to public charging.
- The Ministry of Housing and Urban Affairs (MoHUA) has made amendments to the Model Building Byelaws (MBBL) 2016 making provisions for establishing electric vehicle charging infrastructure. The guidelines act as a guiding document for State Governments to incorporate the norms and standards of EV charging infrastructure in their respective Building Bye Laws. States like Telangana have moved forward and mandated all new buildings constructed in the state to be EV-ready.

Based on the strategies deployed in China and the U.S., a more ambitious and sustained set of policy interventions in India should include:

- EV charging infrastructure and EV-"make-ready" investments as part of India's utility reform and smart grid infrastructure investments
- Improving utilization of chargers through appropriate siting so that the chargers are used by more EV drivers. Another way to increase utilization is to build charging stations that support different charging connectors like CCS, CHAdeMO, GB/T.
- Availability of financing options like accessibility to low interest loans to set up charging stations can help the charger owner-operators during the initial low utilization years.
- Instituting state EV-readiness building code requirements based on the national Model Building Byelaws 2016 to ensure that all new buildings are EV-ready.
- Prepare guidelines to improve coordination around EV charging station deployment by establishing processes and communication requirements for cities and states.
- Following in the footsteps of automakers, encourage oil companies to set up EV chargers. Shell, that has started converting some of its fuel stations in UK to EV charging stations, can be a good example for Indian oil companies like Bharat Petroleum, Hindustan Petroleum, and Indian Oil Corporation Limited to diversify their portfolio.[143]
- Improve consumer awareness and education through engagement with non-profit organizations, utilities, and state-level funding programs.

Source: Shanker S., Flickr

Key Takeaways

- To unleash utility investments, it is critical that state and national policy provide direction for utilities to invest in EV programs, including charging infrastructure. Utilities are increasingly seeing the benefits to their bottom-lines and their customers through increasing electricity sales and increasing the efficiency of the electrical grid through vehicle-grid integration. EV integration can also allow more renewable energy into the grid, which helps utilities meet renewable purchase targets and generates nonmonetary benefits such as energy security and environmental and social benefits.
- Recently, public utilities in California have reconsidered the design of demand charges – a monthly fee to commercial and industrial users based on the highest amount of power drawn. These demand charges can be cost-prohibitive for projects with many DC fast chargers. It is estimated that design changes and caps could reduce electricity bills by 30-50% for some public bus and commercial truck fleets as well as site hosts of DC fast charging stations.[144]
- For charging infrastructure service providers, strategies to improve the economics include increasing revenue, decreasing capital costs and operating costs, achieving higher utilization, capturing other revenue streams via advertising or site-host network fees, and increasing regulatory certainty. Many of these variables are affected by both utility programs and government policies.
- A coalition of organizations – including environmental organizations, consumer groups, organized labor, charging infrastructure providers, and automakers – are promoting a change to utility business models where utilities, as a normal course of business, cover the installation and costs of “make-ready” infrastructure involving the distribution system upgrade, wiring, trenching, conduits, and upgrades on the utility side of the meter up to a maximum cap level. The changes will allow customers to focus on simply the wiring from the meter to the infrastructure site, the costs of the electric vehicles supply equipment (EVSE), and the installation. One estimate is that this could reduce the costs of the charging infrastructure projects by an average of 40% in one utility territory.[145]
- Government agencies can play a critical role in supporting broader EV adoption by establishing EV infrastructure incentive programs. These programs can work to decrease capital costs, provide low-interest loans to charging service providers, require vehicle manufacturers to offer EVs for sale, and establish EV-ready building codes.
- Government agencies also play a critical role in facilitating coordination among various actors – including state and local government – as well as in providing public education and outreach.

Charging Service Providers

There are several key strategies employed by charging infrastructure providers to improve the business case for investment in charging infrastructure. These generally fall into the categories of increasing revenue, decreasing capital costs, decreasing operating costs, and decreasing the cost of funds. Figure 11 below presents a visualization of these forces and this section further describes each of them.

Figure 11: Factors that Affect the Business Case of Charging Infrastructure (Source: NRDC, Atlas Public Policy, 2020)

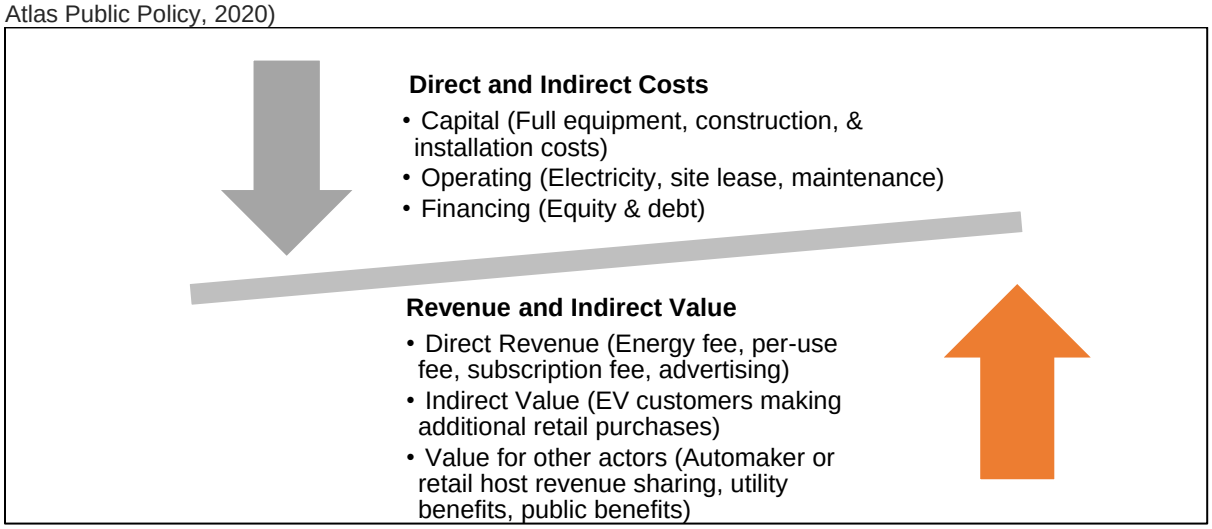


Figure 11 summarizes the key strategies for improving the business case for charging infrastructure investment. The following sections further describe each strategy

Increasing Revenues through Value Capture and Higher Utilization

There are several strategies for increasing charging station revenues both directly – by generating more revenue through higher station utilization– and indirectly, by tapping into indirect values created by charging stations such as increased retail sales by drivers who shop while they charge. Strategies for increasing direct revenues and indirect values are described below.

Direct and Indirect Value Capture

Direct revenues are generated directly by the provisioning of charging services such as energy use fees, per-use fees, subscription fees, and advertising fees. Indirect values are values generated by EVs that can be turned into revenue for charging station owner-operators (see figure 12).

One source of indirect value is from increased retail sales by drivers who shop while they charge, similar to the business model for gasoline convenience stores.[146] A recent report analyzing the business case for charging stations in New York found that monetizing indirect value from retail sales increased the stations' profitability by between seven and 250%.[147] Similarly, charging stations installed at popular tourist destinations may increase tourism and business at those locations.

The additional value generated for other actors in the ecosystem can include increased vehicle sales for automakers, increased sales for retail and tourism businesses, benefits for electric

utilities such as increased electricity sales and vehicle-grid integration (VGI) benefits, and societal benefits such as reduced air pollution and improved energy security.[148] The large charging infrastructure investments made by electric utilities, government agencies, and automakers show that these values – real and perceived – can be quite significant.

Figure 12: Sources of Revenue and Value for Charging Stations (Source: NRDC, Atlas Public Policy, 2020)

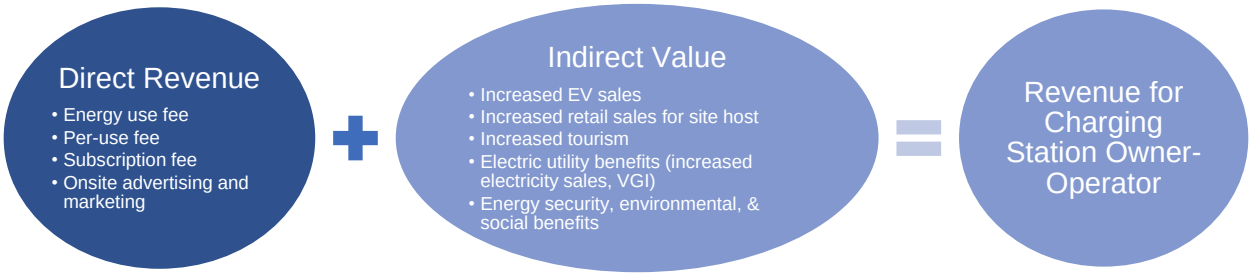


Figure 12 visualizes the pairing of direct revenue and indirect value to enhance the charging station business case.[149]

Higher Utilization Strategies: Siting and Multiple Charging Connectors

The location of a charging station has a significant impact on its utilization and, therefore, its direct revenue and indirect value. For Level 2 charging, siting stations in urban areas where drivers are likely to park for an hour or longer can help to maximize utilization. For DC fast charging, well signed, visible stations which can be located via digital applications / google and sited along major traffic corridors can help maximize utilization. For example, data collected between January 2013 and December 2013 on ten DC fast charging stations located along Interstate 5 in Washington state revealed that these stations all had high utilization rates, ranging from 18.3% to 30.6%.[150] Locating DC fast charging near high-mileage vehicles for ride-hail services can also help maximize utilization. Maven Gig, a mobility service provider that offers unlimited EVgo DC fast charging and rents Chevrolet Bolt EVs to ride-hail drivers for a weekly fee, found that DC fast charging utilization by its ride-hail customers was very high. Within the companies launch in 2017 to August 2018 there were about 223,000 DC fast charging events and 6.59 million kilowatt-hours used.[151] In general, identifying the best sites for charging stations, especially DC fast charging stations, can be complicated and expensive and often requires analysis of traffic patterns, demographics, and electric system requirements in order to identify the best sites.

Another strategy to increase utilization is for installed charging equipment to support more than one charging connector standard and for charging sites to include more than one station. Three fast charging connectors exist in the United States: the CHAdeMO standard (supported by Nissan, Mitsubishi, and Kia); the SAE J1772 Combo standard (supported by nearly all American- and European-manufacturers and some Asian manufacturers); and Tesla's proprietary connector.[152] Supporting only one standards limits the number of vehicles that can use the charging station and therefore, can decrease station utilization. In addition to supporting more than one connector, sites should have more than one station to maintain a high level of reliability for customers. The Electrify America DC fast charging network requires a minimum of four and a maximum of 10 chargers per site.[153] Since 2016, fewer than 17% of charging sites installed only supported the CHAdeMO or SAE Combo connector while over half of charging sites supported a single connector until that point. The early days of the EV market in United

States were likely harmed in some ways by the deployment of single-station sites that only supported one charging connector.

One final approach can be to have multiple parties utilize the same charging stations. For example, a bus depot could have charges for overnight bus charging and those could be available for public or TNC or other dedicated fleet use during the day. EVgo, one of the largest fast charging public network in the U.S., discovered that there was complementarity use between when Uber drivers used their network and when commuters used it – so they made a program that attracted both during different parts of the day to increase utilization.

Installation Cost Efficiencies

Siting multiple stations at the same site can bring down capital costs of charging infrastructure by spreading out fixed, per-site costs. For example, utility interconnection charges can be costly but may not increase with multiple charging stations at the site. Other fixed, per-site costs include the site identification process and the staging of construction. The EV Project, a federally funded charging infrastructure initiative, found that siting choices, including siting multiple stations at one site, was a key driver of lower cost projects.[154]

Regulatory Certainty

In the U.S., state legislatures or public utility commissions are increasingly clarifying that charging infrastructure operators can charge energy-based fees without being subject to electricity delivery regulation, as such regulation can have a significant impact on a project's costs and ability to earn revenue.[155] As of October 2019, 23 states have provided this certainty and declared that charging infrastructure will not be regulated as an electric utility unless it acts like an electric utility, by doing things such as procuring electricity on the wholesale market.[156] Many of these decisions were supported by charging service providers who requested clarity that they would not be regulated as electric utilities. In states where public utility commissions have not issued decisions, charging providers may use time-based fees, per-session fees, or subscription-based fees. Companies such as Tesla and Blink state a preference for charging energy-based fees in their fast charging networks and apply such fees wherever regulations permit them to do so.[157]

Government Agencies

EVs can also reduce air pollution, create energy security, environmental, and social benefits, which government agencies are often responsible for providing. Indirect values may motivate agencies as well as electric utilities to provide incentives to charging station owner-operators. Incentives can include rebates; make-ready investments or agencies may invest in charging stations themselves if permitted to do so by state regulation.

Decreasing Capital Costs

Decreasing capital costs through grants and rebates, low-interest loans, electric utility partnerships, building codes and standards, and installation cost efficiencies are key strategies that government agencies can initiate to facilitate charging infrastructure deployment.

In the U.S., a total of 27 states have offered financial incentives for the purchase or installation of EV charging infrastructure; 13 states have offered grants or rebates and nine states have offered tax credits. Figure 14 below shows which states have provided these financial incentives. The value of these financial incentives and the parties who are eligible to receive them vary significantly. For example, some of these programs are small and geared toward

residential charging stations, such as Arizona's $75 tax credits which were available to individuals who installed a home charging station. Other programs offer much higher incentives for larger entities, such as Massachusetts' Electric Vehicle Incentive Program, which offers grants as high as $50,000 for the cost of Level 1 or Level 2 workplace charging stations.[158]

Figure 14: State and Local Government Incentives (Source: Atlas Public Policy, 2019)

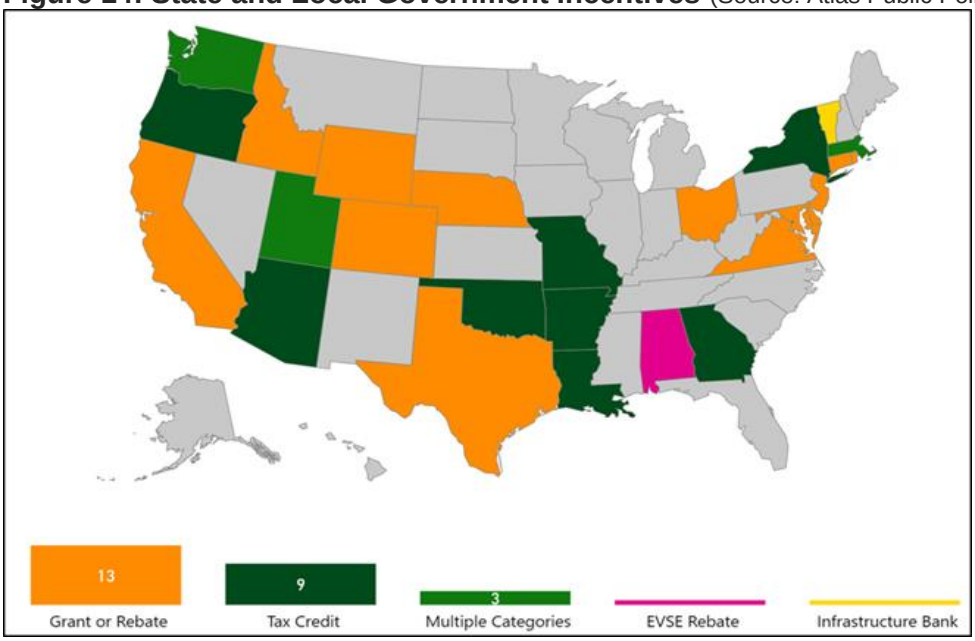


Figure 14 shows which states offer various types of financial incentives for the purchase of installation of EV charging infrastructure.[159]

Low-interest loans can also help to increase the likelihood of profitability by helping charging station owners cover the operating costs of the charging station owner-operator.[160] This can be particularly helpful, while station utilization rates are still low. Since the presence of charging infrastructure can help spur increased EV adoption and higher charging station utilization rates, making charging stations affordable for owner-operators while utilization is low is important to increase utilization.[161] Nebraska, Utah, Virginia, and Vermont all offer loan programs to help fund EV charging infrastructure.[162] While these programs can help charging station owners cover operating costs, it is important to note that the borrower must still repay the loan, which depends on the project's ability to bring in enough revenue to cover upfront and operating costs over the life of the equipment.[163]

While incentives are available to procure and install charging stations, focus should also be on the "soft costs". Soft costs can accrue and the costs of permitting delays, utility interconnection requests, compliance with a balkanized framework of regulations, and the reengineering of projects, among others, can become significant cost drivers that sink the project.[164]

Manufacturer EV Sale Requirements and Consumer Purchase Incentives

Ensuring minimum deployment levels of EVs can help address the "chicken or egg" dilemma around the scale, speed, and scope needed for EV charging infrastructure investments. Policies that spur EV adoption, such as manufacturing requirements to offer EVs for sale as well as consumer/fleet incentives for vehicle purchases, can increase utilization at existing charging infrastructure and encourage new investments to meet growing demand.[165] At the same time, the increased deployment of charging infrastructure can generate new interest in EVs and

alleviate concerns potential buyers have related to charging access. Legislation in Colorado provides a good example of complimentary policies to s spur EV adoption and increase charging station deployment simultaneously. In 2019, Colorado adopted a state zero-emission vehicle (ZEV) requirement that will result in vehicle manufacturers offering more EVs for sale in the state. In the same year, the Colorado state legislature enacted complementary bills to extend the state's generous EV tax credit (HB 1159) and require utilities to file programs, such as charging station deployment, to support widespread transportation electrification (SB 77).[166]

EV-Ready Building Codes and Standards

EV ready building codes and standards can help reduce the capital costs of charging infrastructure investment because retrofitting buildings for EV charging is generally more costly than building EV ready infrastructure during construction. Analysis conducted using data from the California Building Standards Commission estimates that EV ready retrofits are twice as expensive as building EV ready infrastructure during construction. EV ready building codes can require a certain percentage of parking spots to have charging stations or require a certain percentage of parking spots to be equipped with the necessary electrical equipment to install a charging station, such as an electrical circuit with enough capacity as well as conduits and wires. The Plug-in Electric Vehicle Collaborative recommends that 10% of parking spots at residential buildings be dedicated to EV charging.[167] Several states and cities have adopted EV ready building codes. For example, California requires all new multi-family dwellings and non-residential developments to have EV infrastructure, New York City requires newly constructed garages and open lots to have EV ready hardware at least 20% of parking spots, and the city of Seattle recently established requirements that all new buildings with off-street parking, such as garages, must have EV charging infrastructure.[168]

In China, some cities have also requested a certain proportion of charging piles or have reserved charging lines to be built in new residential compounds and parking lots in office buildings to pave the way for large-scale promotion of EVs in the future.

Table 4: Ratio of Charging Parking Spaces for Office and Residential Buildings
(Source: Government of India Ministry of Power)

No.	City	New residential compounds	New office buildings
1	Beijing	100%	25%
2	Shanghai	10%	10%
3	Shenzhen	10%	10%
4	Hefei	10%	20%

This table outlines the city requirements on the ratio of charging parking spaces in residential compounds and office building.[169]

Overcoming Barriers to Coordination

One of the key challenges to deploying charging infrastructure has been the logistical challenges and needs of various charging infrastructure providers, utilities, government agencies, automakers, and site hosts. Several historical and on-going challenges are highlighted from the U.S. and China, as well as examples of efforts to overcome those barriers.

China
Coordination among the stakeholders remains one of the major challenges in China. Government mandates such as building codes, evaluation mechanisms, and incentive programs are the most effective tools to facilitate coordination among property management, utilities, and charging infrastructure providers. Utilities in China are not allowed to adjust rates or tariffs. Such adjustments must be made through the pricing bureau, so designing EV-specific rates are generally very challenging in China. However, several think-tanks, including NRDC, have issued reports proposing that pricing bureaus and utilities have EV-specific rates or tariffs.

United States
To ensure improved coordination around EV charging station deployment, California enacted a law in 2015 to streamline EV charging station permitting by establishing processes and communication requirements for cities and counties.[170] A guidebook was developed by the Office of the Governor to help facilitate information for relevant authorities having jurisdiction involved with siting, permitting, connecting to the grid, construction and review.

Policies to Improve Consumer Education
A lack of consumer awareness continues to be a major barrier to EV adoption and charging infrastructure growth. Many consumers remain unaware of the potential savings from owning and operating an EV, the suitability of an EV for their transportation needs, and the improvements in the performance of the technology when compared to a gasoline vehicle. A study conducted by the University of California at Davis found that from 2014 to 2017, there was no increase in consumer awareness related to EV model availability, charging infrastructure availability, and EV incentive availability.[171] A similar situation exists in China in terms of a lack of consumer awareness. Below are entities who are well positioned to assist with this barrier in the U.S. or/and in China:

- **Non-profit organizations** can use their trusted voice to spread EV awareness. Veloz, a California-based non-profit, focused on consumer education spawned from a state-sponsored effort in the early days of the EV market to encourage dialogue among industry, government, and non-profit organizations.[172] iCET, a Beijing-based non-profit, has been also working on improving consumer awareness in China. iCET's BestEV project has been closely working with consumers and industry experts to increase consumer awareness.[173]
- **Electric utilities** can increase awareness by leveraging their existing customer relationships and conducting consumer awareness campaigns. For example, in Portland, Oregon, the EV-focused non-profit organization, Forth, is working with Portland General Electric to spread awareness of the utility's approved EV programs. Utility-led consumer awareness campaigns are rare in China, but utilities in many cities and provinces have EV service companies that are subsidiaries of utilities to provide charging infrastructure and services directly to customers.
- **States (U.S.)** can use public funds to support education and awareness campaigns. For example, California plans to use $2 million of Electrify America funds to launch an EV awareness campaign.[174]

These campaigns would benefit from components that directly engage auto dealers as they have a significant influence over EV sales through their control of model availability, customer promotions, and other sales strategies. A survey conducted by the Sierra Club found that customers at over 680 dealerships in all 50 states revealed that there are currently significant shortcomings in the EV car-buying experience. Survey results found that 33% of the time, the salesperson at the dealership did not discuss federal or state tax credits, 50% of the salespeople provided no information on charging an EV, and 14% of the time, survey participants who asked to test drive an EV were told that the EV onsite was not sufficiently charged.[175] Additionally, a literature review on consumer awareness and outreach on EVs, conducted by ICCT (2017), identified initiatives such as public-private partnership educational programs and ride-and-drive events to both consumers and fleet owners. The activities were conducted by non-profit groups, city and state government agencies, automakers, and charge provider companies. Information tools have also been developed to provide cost comparisons, public charger location, incentives, and model availability. Other strategies identified include regional planning processes around EV and infrastructure, EV workforce development programs, awards and recognition, auto dealer awareness activities, and public events (e.g. National Drive Electric Week).[176]

Source: Kahunpule Michael Johnson, Creative Commons

Electric Utilities

Many utilities in the U.S. are now recognizing that EVs can create benefits to their bottom-lines and their customers by increasing electricity sales, increasing the efficiency of the electrical grid through VGI, feeding more renewable energy into the grid and helping meet obligatory renewable purchase targets. EVs also generate nonmonetary benefits that electric utilities are often tasked with providing, such as energy security and environmental and social benefits. In order to capture the direct and indirect values, electric utilities in the U.S. may offer incentives to charging station owners, such as equipment rebates or make-ready investments or they may invest in charging stations themselves, if permitted to do so by state legislation and regulation.[177] Utility EV programs may also involve offering specific EV tariffs or rates, education and outreach to utility customers, as well as incentives for EV purchases.

Activating Utilities to Establish EV Programs

Direction from U.S. state legislatures or from the state utility commissions are often necessary for utilities to play a proactive role in the development of utility-EV programs. In some cases, allowances for utilities to recover costs associated with the EV programs in the form of rates was also necessary. Diverse coalitions – consisting of environmental organizations, community groups, vehicle manufacturers, technology companies, utilities, charging infrastructure

providers, organized labor, and consumer advocates – have called for and supported policymaker's efforts calling upon utilities to invest.[178]

Similarly, in China the national government's target setting and directives have been essential to having state-owned utilities invest directly in charging infrastructure while also entering into joint ventures with private infrastructure providers.

Types of infrastructure-related investments: Utility investment has emerged as a critical part of the buildout of EV charging infrastructure. In the U.S., utility commissions across 26 states have approved utilities to move forward with $1.6 billion in investments with more than $1.3 billion in utility proposals filed and awaiting approval.[179] Almost $800 million of the utility EV programs approved in the U.S. –predominantly in California - are focused on "make-ready" investments where the utility provides all of the electrical equipment and services necessary for the installation of the charging station, including transmission and distribution infrastructure, meters, panels, conduits, and charger.[180] Other types of utility investments in charging infrastructure include full utility ownership of the charging equipment, investment in just the distribution infrastructure required for the charging station (this is similar to make-ready investment but does not include equipment beyond the utility meter), and utility-issued financial incentives for non-utility entities to use for charging station installations.

New revenue: For utilities, electric transportation represents increased electricity sales from a load that can largely be off-peak or readily shifted through time-of-use pricing. EV customers provide additional revenue to utilities often at a minimal cost – especially because EVs tend to get charged overnight when people are sleeping and there is plenty of spare capacity on the grid. That means that accommodating EVs has resulted in little marginal costs for utilities while representing a significant new revenue stream. In many jurisdictions across the U.S., regulated utilities are often required to return excess revenues to all customers in the form of lower electricity rates and electricity bills. A recent report by Synapse Energy Economics highlights the ability of EV charging to generate value for utilities. The report found that in the Pacific Gas & Electric and Southern California Edison service territories, the two service territories with the greatest number of EVs in the United States, EV charging revenue exceeded EV charging costs to the utilities by $584 million, demonstrating the ability of EV charging to put downward pressure on electricity rates.[181]

Utility Programs to Decrease Operating Costs

Operating costs for charging infrastructure include electricity costs, site control costs (site lease), and maintenance costs. Dynamic rate schedules that offer lower electricity rates during off-peak hours can help lower the cost of electricity for site hosts who are able to charge exclusively or mainly during off-peak hours. As discussed earlier in this report, the cost of electricity may be particularly high for DC fast charging stations due to demand charges. In order to help lower this operating cost, some states have established policies to exempt DC fast charging stations from demand charges or to place caps on demand charges. For example, Minnesota utility, Xcel Energy, established a "demand limiter" that effectively caps customer bills to an average price per kilowatt-hour. In addition, California utility, Pacific Gas & Electric recently received Commission approval to offer an EV rate plan where customers would be exempt from demand charges and would instead pay a monthly subscription fee based on their chosen power level and pay for energy on a time-of-use schedule.[182] The changes are expected to decrease monthly costs for EV bus and truck fleets in the utility territory by 30% to 50%.[183]

Utility Vehicle-Grid Integration (VGI) Pilots

EV charging can be particularly beneficial to electric utilities through VGI. As a relatively flexible load, EV charging can often be shifted to off-peak hours. When EVs charge during off-peak hours, they generate revenue for electric utilities without adding to peak demand, helping utilities recover the costs of existing assets without triggering the need for additional electrical generation and infrastructure investment. In recognition of this ability for EV charging to lower electricity rates, many utilities are encouraging EV charging through various means such as dynamic pricing schedules, which offer lower electricity rates to EV drivers during off-peak hours, or through other incentive programs. For example, Consolidated Edison of New York's SmartCharge program allows EV drivers to earn monetary rewards for charging off-peak.[184] In addition to generating electricity revenue during off peak hours, EV charging can provide other grid benefits such as renewables integration and demand response. For example, BMW's ChargeForward pilot is testing the ability to use EV charging to provide demand response, grid optimization, and renewables integration services by paying BMW drivers to participate in various charging behaviors such as opt-in demand response events.[185]

Automakers

Automakers, following in the footsteps of Tesla, are increasingly investing or planning to invest in similar national charging infrastructure. BMW is establishing a charging infrastructure company Lonity in Europe, Volkswagen is establishing Electrify America in the U.S., as part of its settlement of the diesel scandal, and Chinese EV manufacturers like Xpeng Motors also investing in stations.

One source of indirect value for automakers is the increased EV sales spurred by drivers' confidence in the availability of charging stations. A study by the ICCT cites Tesla's Supercharger Network as a demonstration of the potential for charging networks to increase EV sales and generate value for automakers.[186] While it is difficult to quantify the contribution of the charging network to Tesla's market share, it is worth noting that the company invested more than $183 million in its Supercharger network and currently makes up more than half of U.S. EV sales.[187]

Conclusion

The business case for publicly available EV charging both in the United States and China continues to face challenges due to low utilization rates, consumers' low willingness to pay for charging, and high upfront and operating costs of infrastructure, in particular, DC fast charging infrastructure. Key strategies to overcome these challenges include increasing revenue through indirect value capture, decreasing capital costs, and operating costs. Indirect values generated by charging stations, such as increased retail revenue from drivers who shop while charging, are particularly important in order to improve the business case for charging stations. EV charging, especially off-peak charging, can bring down electricity rates and can help bring nonmonetary benefits such as energy security, environmental and social benefits. These benefits have incentivized utilities to play a more central role in charging infrastructure deployment. Promising ways to increase charging station utilization include siting charging stations strategically, enhancing charging station accessibility by supporting multiple charging standards, and encouraging EV adoption through incentives such as tax credits.

Federal, state and local governments have provided an important source of funding to help lower the capital costs of charging infrastructure through grants, rebates, tax incentives, and low interest loans. Electric utility investment in make-ready infrastructure has also played an important role in lowering the capital costs of charging stations. In addition, EV ready building codes and standards can significantly lower the installation costs of charging stations. Particularly in the U.S., high demand charges can represent a significant operating expense for DC fast charging stations, especially as station power ratings increase and utilization remains low. Some utilities have created rate schedules to exempt or limit demand charges for DC fast charging stations. Other factors, such as regulatory certainty regarding EV charging station jurisdiction and consumer education can also help facilitate greater EV charging infrastructure deployment.

Source: Opengridscheduler/Grid Engine, Flickr

Appendix

Inductive Charging & Battery Swapping

In addition to the charging standards described above, infrastructure deployment strategies can include battery swapping and inductive charging. While battery swapping has not been successful for passenger vehicles and larger vehicles in the United States, it has had some success with smaller vehicles such as two and three-wheelers in countries such as India, Japan, France, and Germany.[188] Battery swapping's lack of success in the United States is due to several core logistical challenges such as the weight and bulk of the batteries for the four-wheel segment and the need in most cases to disconnect and reconnect various connections, such as coolant pipes. In addition, automakers are unlikely to share their proprietary battery design technologies with other automakers, making the standardization of battery packs across vehicle types unlikely, limiting EV drivers to swapping stations that work for their vehicle types.[189] In 2013, Tesla opened a battery swapping station but the station shuttered in 2016.[190] Where battery swapping has had success, it brings two key benefits. First, it decreases the upfront cost of an EV by allowing the customer to lease the battery and/or subscribe to a battery swapping network instead of purchasing the battery outright. Second, battery swapping decreases downtime for EV drivers since it takes less time than charging a battery with today's recharging technology.

In China, there exist two major battery swapping service providers (excluding the State Grid): Aulton which has 167 battery swapping stations, followed by NIO which has 123 battery swapping stations. Both companies have only been in operation for a couple of years, and the business cases for battery swapping stations have not yet been proved.

A less common way to charge a vehicle is wireless, or inductive charging. One potential benefit of inductive charging is that it more compatible with autonomous vehicles than plug-based charging stations. Inductive charging also has the potential to provide "dynamic charging" by embedding chargers in roadways, which could extend the range of EVs with smaller, lighter batteries.[191] Inductive charging is being developed and tested; however, the technology faces several challenges that make it significantly less common than plug-based charging. Most inductive charging technology is more expensive than plug-based technology with an average cost between $350 per kilowatt to $475 per kilowatt. Inductive charging has not yet been able to reach the power ratings of Level 2 or DC fast charging stations, with most stationary wireless charging systems rated between three and seven kilowatts. Wireless charging is also currently less efficient than plug-based charging. The company Evatran, which produces the only commercially available wireless charging product, states that its product, the plug less charging system, is about 12% less efficient than a

Source: Xiao, Cao, Flickr

conventional Level 2 station. In addition, because charging efficiency relies on proper alignment of the vehicle with the charging pad, wireless charging requires additional sensors and other technology, contributing to its high costs compared to plug-based charging. Finally, dynamic inductive charging faces additional technological challenges associated with electrifying roads to enable charging.[192]

In the United States there has not been a lot of public funding for inductive charging projects. Of over $800 million of public funding for charging infrastructure identified on EV Hub, an information service provided by Atlas Public Policy, only about $9 million from three states has gone toward inductive charging and all of these funds have been for transit bus applications.[193] Automakers such as BMW and Nissan are working on developing the technology for light-duty vehicles, however these developments are small-scale and in early development. BMW is launching an inductive charging pilot for passenger vehicles in California that is limited to only 200 drivers and Nissan is working on developing a wireless charging solution, but nothing is complete yet.[194]

With time and innovation, new charging technologies may be developed and commercialized. Policymakers should determine when technologies have been sufficiently developed to integrate into their existing policy frameworks and work to reduce barriers to their introduction.

Demonstration of wireless inductive charging in Tokyo Japan. Source: NJo, Creative Commons

Endnotes

[1] NITI Aayog, Rocky Mountain Institute*, India's Electric Mobility Transformation: Progress to Date and Future Opportunities*, April 2019.
[2] CRISL, "Getting Charged: Two and three-wheelers to spearhead electric vehicle adoption," https://www.crisil.com/content/dam/crisil/our-analysis/reports/Research/documents/2020/02/getting-charged.pdf
[3] Autocar Pro News Desk, "Low-speed electric scooters make up for bulk of EV sales in India in FY2020," Autocar. Professional*,* https://www.autocarpro.in/author/profile/authorname/autocar-pro-news-desk/authorid/19 (Accessed April 20, 2020); Mayank Dhingra, "India auto sales crash 18% in FY2020; OEMs stare at a difficult FY2021," Autocar Professional, 13 Apr 2020, https://www.autocarpro.in/analysis-sales/india-auto-sales-crash-18-in-fy2020;-oems-stare-at-a-difficult-fy2021-56150 (Accessed June 23, 2020)).
[4]Department of Heavy Industry, RMI India, "Building in Electric Bus Ecosystem in Indian Cities", 2019, https://rmi.org/wp-content/uploads/2020/02/ebus_report.pdf.
[5] Autocar Pro News Desk, "Low-speed electric scooters make up for bulk of EV sales in India in FY2020," Autocar Professional*,* https://www.autocarpro.in/author/profile/authorname/autocar-pro-news-desk/authorid/19 (Accessed April 20, 2020); Auto Story, "Indian automobile industry feels BS-VI and coronavirus jitters, FY20 domestic volumes drop by 18pc", April 2020, https://yourstory.com/automotive/indian-automobile-industry-volumes-drop-18-pc-fy-20-coronavirus#:~:text=As%20per%20the%20latest%20data,19%20stood%20at%2026%2C266%2C179%20units.
[6] Mandal, S. "Turbo-Charging EV Adoption: The Keys To Success In Indian Market,"https://inc42.com/datalab/turbo-charging-ev-adoption-the-keys-to-success-in-indian-market/(Accesed March 31, 2020)).
[7] Ministry of Heavy Industries and Public Enterprises, "Notification: Scheme for Faster Adoption and Manufacturing of electric Vehicles in India Phase II, https://dhi.nic.in/writereaddata/UploadFile/publication NotificationFAME %20II%208March2019.pdfhttps://dhi.nic.in/writereaddata/UploadFile/publication. NotificationFAME %20II%208March2019.pdf; Singh, S., "EVs to get 2,600 Charging Stations," The Economic Times, https://auto.economictimes.indiatimes.com/news/industry/evs-to-get-2600-charging-stations/74088504.
[8] Priya, S. "India's electric story to continue, to be dominated by light mobility post Covid-19," The Economic Times, https://auto.economictimes.indiatimes.com/news/industry/indias-electric-story-to-continue-to-be-dominated-by-light-mobility-post-covid-19/75284206.
[9] Priya, S. "India's electric story to continue, to be dominated by light mobility post Covid-19," The Economic Times, https://auto.economictimes.indiatimes.com/news/industry/indias-electric-story-to-continue-to-be-dominated-by-light-mobility-post-covid-19/75284206.
[10] Ministry of Heavy Industries and Public Enterprises, "Notification: Scheme for Faster Adoption and Manufacturing of Electric Vehicles in India Phase II, https://dhi.nic.in/writereaddata/UploadFile/publication NotificationFAME %20II%208March2019.pdfhttps://dhi.nic.in/writereaddata/UploadFile/publication. NotificationFAME %20II%208March2019.pdf; Singh, S., "EVs to get 2,600 Charging Stations," The Economic Times, https://auto.economictimes.indiatimes.com/news/industry/evs-to-get-2600-charging-stations/74088504
[11] Government of India Press Information Bureau, National Mission on Transformative Mobility Press Release, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1567807; DataLabs, " Vehicle Market Outlook Report 2020," https://datalabs.inc42.com/product/electric-vehicle-market-outlook-report-2020/?itm_medium=website&itm_source=ev-affordability&itm_campaign=datalabs-reports&itm_content=ev-report.
[12] Hove, A., Sandalow, D., "Electric Vehicle Charging in China and the United States," Columbia SIPA Centre on Global Energy Policy, https://energypolicy.columbia.edu/sites/default/files/file-uploads/EV_ChargingChina-CGEP_Report_Final.pdf.
[13] Hove, A., Sandalow, D., "Electric Vehicle Charging in China and the United States," Columbia SIPA Centre on Global Energy Policy, https://energypolicy.columbia.edu/sites/default/files/file-uploads/EV_ChargingChina-CGEP_Report_Final.pdf.
[14] Xiao,W., et al. *Exposure to air pollution and COVID-19 mortality in the United States: A nationwide cross-sectional study*, April 2020; Limay, V. "*Polluted air makes the coronovirus even deadler," NRDC Expert Blog* https://www.nrdc.org/experts/vijay-limaye/polluted-air-makes-coronavirus-even-deadlier.
[15] Vidhi,R., Shrivastava, P. *A review of electric vehicle lifecycle emissions and policy recommendations to increase EV penetration in India*. 2018, Energies, Vol. 11, p. 483.
[16] National Renewable Energy Laboratory, *National Economic Value Assessment of Plug-in Electric Vehicles*, Volume 1, December 2016; ICF, "Comparison of Medium- and Heavy- Duty Technologies in California," https://caletc.com/wp-content/uploads/2019/12/ICF-Truck-Report_Final_December-2019.pdf.
[17] China Electric Vehicle Charging Infrastructure Promotion Alliance, https://mp.weixin.qq.com/s/JQ9_ rmaSailqtM7SIQ4e8Q;.

[18] EUSME, “The Electric Vehicle Market in China, 2019,” http://ccilc.pt/wp-content/uploads/2017/07/The-Electric-Vehicle-Market-in-China_vF.pdf; Hove, A., Sandalow, D. “Electric Vehicle Charging in China and the United States,” Columbia SIPA Centre on Global Energy Policy, https://energypolicy.columbia.edu/sites/default/files/file-uploads/EV_ChargingChina-CGEP_Report_Final.pdf.
[19] Atlas Public Policy, “Charging Ports Increased by 40 Percent Between 2018 and 2019,” https://www.atlasevhub.com/weekly_digest/charging-ports-increased-by-40-percent-between-2018-and-2019/
[20] China Electric Vehicle Charging Infrastructure Promotion Alliance, 2019, http://www.evcipa.org.cn; Hove, A., Sandalow, D., “Electric Vehicle Charging in China and the United States,” Columbia SIPA Centre on Global Energy Policy, https://energypolicy.columbia.edu/sites/default/files/file-uploads/EV_ChargingChina-CGEP_Report_Final.pdf.
[21] China Electric Vehicle Charging Infrastructure Promotion Alliance, Press Release November 11,2019, http://www.evcipa.org.cn.
[22] China Electric Vehicle Charging Infrastructure Promotion Alliance, 2019, http://www.evcipa.org.cn; Hove, A., Sandalow, D., “Electric Vehicle Charging in China and the United States,” Columbia SIPA Centre on Global Energy Policy, https://energypolicy.columbia.edu/sites/default/files/file-uploads/EV_ChargingChina-CGEP_Report_Final.pdf.
[23] Atlas Public Policy,“ EV Charging Deployment Dashboard” https://www.atlasevhub.com/materials/ev-charging-deployment/(Accessed October 15,2019)).
[24] Office of Energy Efficiency & Renewable Energy, ”Charging at Home,”https://www.energy.gov/eere/electricvehicles/charging-home (Accessed November 12, 2019)).
[25] Center for Climate and Energy Solutions, *Strategic Planning to Implement Publicly Available EV Charging Stations: A Guide for Businesses and Policymakers.* 2015.
[26]Sawaya, D. *EV Infrastructure: Need and Cost,* California Electric Transportation Coalition, Draft Presentation, 2019.
[27] Ashat Rathi , “Lyft says all rides will be electric cars by the end of 2030,” Fortune, June 17, 2020, https://fortune.com/2020/06/17/lyft-electric-cars-by-end-of-2030/.
[28] Hove, A., Sandalow, D., “Electric Vehicle Charging in China and the United States,” Columbia SIPA Centre on Global Energy Policy, https://energypolicy.columbia.edu/sites/default/files/file-uploads/EV_ChargingChina-CGEP_Report_Final.pdf.
[29] US Department of Energy “Alternative Fuels Data Center,” https://afdc.energy.gov/laws/arra.html (Accessed October 15,2019)).
[30] VW Settlement Clearinghouse “About the Settlement,” https://vwclearinghouse.org/about-the-settlement/ (Accessed October 15,2019)).
[31] Miles Muller, “Reforming Rates for Electric Trucks, Buses, and Fast Chargers, NRDC Expert Blog, May 4, 2020 https://www.nrdc.org/experts/miles-muller/reforming-rates-electric-trucks-buses-fast-chargers.
[32] Muller, M. “Reforming Rates for Electric Trucks, Buses, and Fast Chargers, NRDC Expert Blog, May 4, 2020 https://www.nrdc.org/experts/miles-muller/reforming-rates-electric-trucks-buses-fast-chargers; San Diego Gas & Electric Company, “Transportation Electrification Framework: Proposed-Utility Side EV Infrastructure Tariff”, May 20, 2020; San Diego Gas & Electric Company,” R.18-12-006: Reply Comments of San Diego Gas & Electric Company on the Transportation Electrification Framework Overview,” https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M335/K498/335498387.PDFhttps://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M335/K498/335498387.pdfhttps://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M335/K498/335498387.PDF.
[33] Mandal, S. “Turbo-Charging EV Adoption: The Keys To Success In Indian Market,”https://inc42.com/datalab/turbo-charging-ev-adoption-the-keys-to-success-in-indian-market/(Accesed March 31, 2020)).
[34] Autocar Pro News Desk, “Low-speed electric scooters make up for bulk of EV sales in India in FY2020’ https://www.autocarpro.in/news-national/lowspeed-electric-scooters-make-up-for-bulk-of-ev-sales-in-india-in-fy2020-56197.
[35] China Electric Vehicle Charging Infrastructure Promotion Alliance, http://www.evcipa.org.cn.
[36] Atlas Public Policy, “Charging Ports Increased by 40 Percent Between 2018 and 2019,” https://www.atlasevhub.com/weekly_digest/charging-ports-increased-by-40-percent-between-2018-and-2019/
[37] China Electric Vehicle Charging Infrastructure Promotion Alliance, 2019, http://www.evcipa.org.cn; Hove, A., Sandalow, D., “Electric Vehicle Charging in China and the United States,” Columbia SIPA Centre on Global Energy Policy, https://energypolicy.columbia.edu/sites/default/files/file-uploads/EV_ChargingChina-CGEP_Report_Final.pdf.
[38] China Electric Vehicle Charging Infrastructure Promotion Alliance, Press Release November 11,2019, http://www.evcipa.org.cn.
[39] Atlas Public Policy,“EV Charging Deployment Dashboard” https://www.atlasevhub.com/materials/ev-charging-deployment/(Accessed October 15,2019).
[40] Office of Energy Efficiency & Renewable Energy, ”Charging at Home,”https://www.energy.gov/eere/electricvehicles/charging-home (Accessed November 12, 2019).

[41] Center for Climate and Energy Solutions, *Strategic Planning to Implement Publicly Available EV Charging Stations: A Guide for Businesses and Policymakers.* 2015.
[42] Sawaya, D. *EV Infrastructure: Need and Cost,* California Electric Transportation Coalition, Draft Presentation, 2019.
[43] China Electric Vehicle Charging Infrastructure Promotion Alliance, http://www.evcipa.org.cn; .
[44] Blad, D. "Urban legend: China's tiered city system explained," South China Morning Post, 2016. https://multimedia.scmp.com/2016/cities/ (Accessed January 1, 2020)).
[45] China Electric Vehicle Charging Infrastructure Promotion Alliance, 2019, http://www.evcipa.org.cn; Hove, A., Sandalow, D., "Electric Vehicle Charging in China and the United States," Columbia SIPA Centre on Global Energy Policy, https://energypolicy.columbia.edu/sites/default/files/file-uploads/EV_ChargingChina-CGEP_Report_Final.pdf.
[46] China Electric Vehicle Charging Infrastructure Promotion Alliance, Press Release November 11,2019, http://www.evcipa.org.cn.
[47] Office of Energy Efficiency & Renewable Energy, "Charging at Home,"https://www.energy.gov/eere/electricvehicles/charging-home (Accessed November 12, 2019)).
[48] Atlas Public Policy Charging Deployment Dashboard," https://www.atlasevhub.com/materials/ev-charging-deployment/(Accessed October 15,2019)).
[49] Atlas Public policy Charging Deployment Dashboard," https://www.atlasevhub.com/materials/ev-charging-deployment/(Accessed October 15,2019);Herron, D. "Range Confidence: Charge Fast, Drive Far, with your Electric Car. [Online] 2017. [Cited: January 1, 2020.] https://greentransportation.info/ev-charging/range-confidence/chap4-charging/4-charging-levels.html (Accessed January 1, 2020)).
[50] Atlas Public policy Charging Deployment Dashboard," https://www.atlasevhub.com/materials/ev-charging-deployment/(Accessed October 15,2019)).
[51] Energy Efficiency and Renewable Energy "Charging at Home," https://www.energy.gov/eere/electricvehicles/charging-home.
[52] GreenTechMedia, "WoodMac: Workplace EV Charging is on the Rise," https://www.greentechmedia.com/articles/read/woodmac-ev-charging-is-rise (Accessed November 6, 2019)).
[53] Atlas Public Policy, "Charging Ports Increased by 40 Percent Between 2018 and 2019," https://www.atlasevhub.com/weekly_digest/charging-ports-increased-by-40-percent-between-2018-and-2019/
[54] Atlas Public Policy,"EV Charging Deployment Dashboard" https://www.atlasevhub.com/materials/ev-charging-deployment/(Accessed October 15,2019)).
[55] Atlas Public Policy,"EV Charging Deployment Dashboard" https://www.atlasevhub.com/materials/ev-charging-deployment/(Accessed October 15,2019)).
[56] Sawaya, D. *EV Infrastructure: Need and Cost,* California Electric Transportation Coalition, Draft Presentation, 2019.
[57] The International Council on Clean Transportation, *Quantifying the Electric Vehicle Charging Infrastructure Gap Across U.S. Markets,* 2019.
[58] Atlas Public Policy,"EV Charging Deployment Dashboard" https://www.atlasevhub.com/materials/ev-charging-deployment/(Accessed October 15,2019)).
[59] Center for Climate and Energy Solutions, "Business Models for Financially Sustainable EV Charging Network," https://www.c2es.org/site/assets/uploads/2015/03/business-models-ev-charging-infrastructure-03-15.pdf.
[60] Center for Climate and Energy Solutions, "Business Models for Financially Sustainable EV Charging Network," https://www.c2es.org/site/assets/uploads/2015/03/business-models-ev-charging-infrastructure-03-15.pdf.
[61] China Electric Vehicle Charging Promotion Alliance, http://www.evcipa.org.cn/;.
EV100, NRDC and China, Analysis on Developing a Healthy Charging Service Market for Electric Vehicles in China. s.l. : NRDC, 2019.
[62] Ashat Rathi , "Lyft says all rides will be electric cars by the end of 2030," Fortune, June 17, 2020, https://fortune.com/2020/06/17/lyft-electric-cars-by-end-of-2030/.
[63]China Electric Vehicle Charging Infrastructure Promotion Alliance, Press Release November 11,2019, http://www.evcipa.org.cn.
[64] EV100, NRDC and China, Analysis on Developing a Healthy Charging Service Market for Electric Vehicles in China. s.l. : NRDC, 2019.
[65] China Electric Vehicle Charging Infrastructure Promotion Alliance, Press Release November 11,2019, http://www.evcipa.org.cn.
[66] EV100, NRDC and China, *Analysis on Developing a Healthy Charging Service Market for Electric Vehicles in China.* s.l. : NRDC, 2019.
[67] Chuxing, D. *Leading EV Charging Operators Disconnect Themselves.* s.l. : Kr-Asia, April 1, 2019.
[68] EVCIPARenewable Energy World, "The number of public charging stations for EVs in China surges 50.5% in May,"

https://www.renewableenergyworld.com/2019/07/02/the-number-of-public-charging-stations-for-evs-in-china-surges-505-in-may/.
[69] *China's Ride-Hailing Market Analysis 2019, Easy View, July 2019.*
[70] Wu, K., Zhu, J., Two Chinese EV sharing platforms in $730 million push to fuel growth"https://www.reuters.com/article/us-caocao-fundraising/two-chinese-ev-sharing-platforms-in-730-million-push-to-fuel-growth-sources-idUSKBN1KY0PM (Accessed January 2, 2020)).
[71]Interim Measures of Shenzhen Municipality on the Management of Online Booking Taxi Business Service Management, http://www.sz.gov.cn/en_szgov/laws/content/post_1351345.html.
[72] ANALYSYS, "*China's Ride-Hailing Market Analysis 2019, Easy View, July, 2019*,", ANALYSYS, https://www.analysys.cn/article/detail/20019412 (Accessed July 25, 2020).
[73] The International Council on Clean Transportation, *Quantifying the Electric Vehicle Charging Infrastructure Gap Across U.S. Markets.* 2019.
[74] Atlas Public Policy, "Demographics Dashboard," https://www.atlasevhub.com/materials/demographics/ (Accessed October 19, 2019)).
[75] The International Council on Clean Transportation, *Quantifying the Electric Vehicle Charging Infrastructure Gap Across U.S. Markets.* 2019.
[76] The International Council on Clean Transportation, *Quantifying the Electric Vehicle Charging Infrastructure Gap Across U.S. Markets.* 2019.
[77] Sawaya, D. *EV Infrastructure: Need and Cost,* California Electric Transportation Coalition, Draft Presentation, 2019.
[78] The International Council on Clean Transportation, *Quantifying the Electric Vehicle Charging Infrastructure Gap Across U.S. Markets.* 2019.
[79] Center for Climate and Energy Solutions, *Strategic Planning to Implement Publicly Available EV Charging Stations: A Guide for Businesses and Policymakers.* 2015.
[80] New York State Energy Research and Development Authority, *Assessing the Business Case for Hosting Electric Vehicle Charging Stations in New York State.* 2019.
[81] Center for Climate and Energy Solutions, "Business Models for Financially Sustainable EV Charging Network," https://www.c2es.org/site/assets/uploads/2015/03/business-models-ev-charging-infrastructure-03-15.pdf.
[82] Seattle Department of Transportation, "Electric Vehicle Charging in the Public Right-of-Way," https://www.seattle.gov/transportation/projects-and-programs/programs/new-mobility-program/electric-vehicle-charging-in-the-public-right-of-way (Accessed October 7, 2019); New York City Department of Transportation, "Curbside Level 2 Electric Vehicle Charging," https://nycdotprojects.info/project/839/overview (Accessed October 19, 2019); City of Sacramento, "Electric Vehicle Incentives," http://www.cityofsacramento.org/Public-Works/Electric-Vehicle-Initiatives/Curbside-Charging(Accessed October 10, 2019)).
[83] Seattle Department of Transportation, "Electric Vehicle Charging in the Right-of-Way Permit Pilot (EVCROW): 1.0 Evaluation Report," https://www.seattle.gov/Documents/Departments/SDOT/NewMobilityProgram/EVCROW_Evaluation_Report.pdf (Accessed April, 2020)).
[84] Seattle Department of Transportation, "Electric Vehicle Charging in the Right-of-Way Permit Pilot (EVCROW): 1.0 Evaluation Report," https://www.seattle.gov/Documents/Departments/SDOT/NewMobilityProgram/EVCROW_Evaluation_Report.pdf (Accessed April, 2020)).
[85] Center for Climate and Energy Solutions, *Strategic Planning to Implement Publicly Available EV Charging Stations: A Guide for Businesses and Policymakers.* 2015.
[86] West Coast Green Highway, "West Coast Electric Highway," http://www.westcoastgreenhighway.com/electrichighway.htm Accessed (October 19, 2019)).
[87] National Association of State Energy,"REV West," https://www.naseo.org/issues/transportation/rev-west (Accessed January 1, 2020)).
[88] Quartz, "New York City says electric cars are now the cheapest option for its fleet," https://qz.com/1571956/new-york-city-says-electric-cars-cheapest-option-for-its-fleet/ (Accessed October 20, 2019); Keith T. Kerman " Reducing Maintenance Costs With Electric Vehicles," NYC DCAS NYC Fleet Newsletter, https://www1.nyc.gov/assets/dcas/downloads/pdf/fleet/NYC-Fleet-Newsletter-255-March-8-2019-Reducing-Maintenance-Costs-With-Electric-Vehicles.pdf)).
[89] U.S Department of Energy, " National Plug-In Electric Vehicle Infrastructure Analysis," https://www.nrel.gov/docs/fy17osti/69031.pdf.
[90] EV Shared Mobility, "National Overview of TNC Electrification," http://evsharedmobility.org/national-overview-of-tnc-electrification/ (Accessed October 20, 2019)).

[91] EV Shared Mobility, http://evsharedmobility.org/ (Accessed October 20, 2019)).
[92] EV Shared Mobility, “CITY FACT SHEET: NYC,” http://evsharedmobility.org/wp-content/uploads/2019/05/Sustainable_Mobility_Services_Project_Fact_Sheet_NYC.pdf (Accessed January 1, 2020)).
[93] California Eclectic Transportation Coalition, “Comparison of Medium- and Heavy-Duty Technologies in California: Summary for Policymakers,” https://caletc.com/summary-for-policymakers/ (Accessed 1,2020).
[94] California Eclectic Transportation Coalition, “ Comparison of Medium- and Heavy-Duty Technologies in California: Summary for Policymakers,” https://caletc.com/summary-for-policymakers/ (Accessed 1,2020)).
[95] Smith, C. “Total Cost of Ownership for Medium- and Heavy-Duty Electric Vehicles,” Atlas Public Policy, https://atlaspolicy.com/rand/electric-trucks-and-buses-overview/.
[96] North American Council for Freight Efficiency, “Amping Up: Charging Infrastructure For Electric Trucks.,” https://nacfe.org/future-technology/amping-up-charging-infrastructure-for-electric-trucks/ (Accessed November 14, 2019)).
[97]Government of India Press Information Bureau, National Mission on Transformative Mobility Press Release, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1567807; DataLabs, “ Vehicle Market Outlook Report 2020,” https://datalabs.inc42.com/product/electric-vehicle-market-outlook-report-2020/?itm_medium=website&itm_source=ev-affordability&itm_campaign=datalabs-reports&itm_content=ev-report.
[98] Hove, A., Sandalow, D., “Electric Vehicle Charging in China and the United States,” Columbia SIPA Centre on Global Energy Policy, https://energypolicy.columbia.edu/sites/default/files/file-uploads/EV_ChargingChina-CGEP_Report_Final.pdf.
[99] US Department of Energy “Alternative Fuels Data Center,” https://afdc.energy.gov/laws/arra.html (Accessed Outober 15,2019).
[100] EUSME, “The Electric Vehicle Market in China, 2019,” http://ccilc.pt/wp-content/uploads/2017/07/The-Electric-Vehicle-Market-in-China_vF.pdf.
[101] ChinaEV100, NRDC. *Analysis on Developing a Healthy Charging Service Market for Electric Vehicles in China.* s.l. : NRDC, 2019.
[102]EUSME, “The Electric Vehicle Market in China, 2019,” http://ccilc.pt/wp-content/uploads/2017/07/The-Electric-Vehicle-Market-in-China_vF.pdf; Hampel, C. “Largest utilities in China invest in charging infrastructure,” inhttps://www.electrive.com/2020/04/15/utilities-in-china-invest-in-charging-infrastructure/ .
[103] Hove, A., Sandalow, D. “Electric Vehicle Charging in China and the United States,*”* Columbia SIPA Center on Global Energy Policy, 2019. https://energypolicy.columbia.edu/sites/default/files/file-uploads/EV_ChargingChina-CGEP_Report_Final.pdf; *China State Grid, “Discussion with NRDC”,2019.*
[104] Hampei, C. *Largest Utilities in China invest in Charging Infrastructure.* April 15, 2020.
[105] Stringer, D., et, al. *“China Beats U.S. 8-1 When It Comes to Charging Electric Cars,” Bloomberg,* https://www.bloomberg.com/news/features/2019-10-15/china-electric-car-chargers-fleet-outpaces-u-s-ev-stations (Accessed October 15, 2019)).
[106] Atlas Public Policy, “Public Agency Requests & Funding Awards,” https://www.atlasevhub.com/materials/public-agency-requests-funding-awards/; Atlas Public Policy, “Electric Utility Filings Dashboard,” https://www.atlasevhub.com/materials/electric-utility-filings/.
[107]Atlas Public Policy, “Global Private Investment Dashboard,” https://www.atlasevhub.com/materials/private-investment/ (Accessed October 15, 2019)).
[108] Tax Policy Center, “Credit Type and Amount,”https://www.taxpolicycenter.org/statistics/credit-type-and-amount.
[109] US Department of Energy “Alternative Fuels Data Center,” https://afdc.energy.gov/laws/arra.html (Accessed October 15,2019)).
[110] Idaho National Laboratory, “Real World Demonstrations - American Recovery and Reinvestment Act (ARRA) Projects,” https://avt.inl.gov/content/demonstrations (Accessed October 15, 2019)).
[111] Atlas Public Policy, “Public Agency Requests & Funding Awards” https://www.atlasevhub.com/materials/public-agency-requests-funding-awards/.
[112] VW Settlement Clearinghouse “About the Settlement,” https://vwclearinghouse.org/about-the-settlement/ (Accessed October 15,2019)).
[113]Atlas Public Policy, “VW Settlement Dashboard,” https://www.atlasevhub.com/materials/vw-environmental-mitigation-fund-tracking (Accessed October 15,2019)).
[114]Atlas Public Policy, “Utility Filings Dashboard,”https://www.atlasevhub.com/materials/electric-utility-filings/ (Accessed October 14, 2019)).
[115] Synapse Energy, “Electric Vehicles are Driving Electric Rates Down,”https://www.synapse-energy.com/sites/default/files/EV-Impacts-June-2019-18-122.pdf.
[116] Atlas Public Policy, “Utility Filings Dashboard,”https://www.atlasevhub.com/materials/electric-utility-filings/ (Accessed October 14, 2019)).

[117] Minnesota Public Utility Commission, “Electric Vehicles,” https://mn.gov/puc/energy/electric-vehicles/ (Accessed October 14, 2019)).
[118] Atlas Public Policy, “Utility Filings Dashboard,”https://www.atlasevhub.com/materials/electric-utility-filings/ (Accessed October 14, 2019)).
[119] Atlas Public Policy, “Global Private Investment Dashboard,” https://www.atlasevhub.com/materials/private-investment/ (Accessed October 14, 2019)).
[120] The Regional Greenhouse Gas Initiative, “The Investment of RGGI Proceeds in 2018,” https://www.rggi.org/sites/default/files/Uploads/Proceeds/RGGI_Proceeds_Report_2017.pdf.
[121] Transportation & Climate Initiative, https://www.transportationandclimate.org/.
[122] Government of India Ministry of Power, https://powermin.nic.in/sites/default/files/webform/notices/scan0016%20%281%29.pdf.
[123] Kane, M. “*China Is Developing New GB/T Fast Charging Standard At 900 kW,” Inside EVS,* https://insideevs.com/news/338620/china-is-developing-new-gb-t-fast charging-standard-at-900-kw/.
[124] Bengt, H. *Reality Check: CHAdeMO fast charging stations still outnumber CCS ones.* s.l. :Green Car Reports, August 20, 2019.
[125] CHAdeMO, “Protocol Development: Constantly Evolving with The Market,”” https://www.chademo.com/activities/protocol-development/ (Accessed October 17, 2019); ANSI Webstore, “Surface Vehicle Standard,” https://webstore.ansi.org/Standards/SAE/SAE17722016J1772)).
[126] Hove, A., Sandalow, D., “Electric Vehicle Charging in China and the United States,*”* Columbia SIPA Center on Global Energy Policy, 2019. https://energypolicy.columbia.edu/sites/default/files/file-uploads/EV_ChargingChina-CGEP_Report_Final.pdf.
[127] Siemens, “Charging Systems for ebuses,” https://new.siemens.com/global/en/products/mobility/road-solutions/electromobility/ebus-charging.html(Accessed November 21, 2019); ChargePoint, “Express Plus: The Future of Ultra-Fast DC Charging,” https://www.chargepoint.com/files/brochures/br-expressplus.pdf.
[128] Hove, A., Sandalow, D., “Electric Vehicle Charging in China and the United States,*”* Columbia SIPA Center on Global Energy Policy, 2019. https://energypolicy.columbia.edu/sites/default/files/file-uploads/EV_ChargingChina-CGEP_Report_Final.pdf.
[129] Hove, A., Sandalow, D., “Electric Vehicle Charging in China and the United States,*”* Columbia SIPA Center on Global Energy Policy, 2019. https://energypolicy.columbia.edu/sites/default/files/file-uploads/EV_ChargingChina-CGEP_Report_Final.pdf.
[130]NRDC, *Reply Comments of the NRDC on Vehicle-Grid Integration Communication Protocol Working Group Energy Division Staff Report.* s.l. : NRDC, 2018.
[131] NRDC, *Reply Comments of the NRDC on Vehicle-Grid Integration Communication Protocol Working Group Energy Division Staff Report.* s.l. : NRDC, 2018.
[132] ElaadNL, *EV Related Protocol Study*, Original Study Report Version 1.1. 2016.
[133] ElaadNL, *EV Related Protocol Study*, Original Study Report Version 1.1. 2016.
[134] Lata, C. *Electric Vehicles’ Role in Reducing Air Pollution*, Society of Energy Engineers and Managers, Energy Managers Magazine, October-December 2019 Issue, Volume 12, No, 4, Page 13.
[135] Center for Climate and Energy Solutions, *Strategic Planning to Implement Publicly Available EV Charging Stations: A Guide for Businesses and Policymakers.* 2015.
[136]Great Plains Institute for the Midcontinent Transportation Electrification Collaborative, “Analytical White Paper: Overcoming Barriers to Expanding Fast Charging Infrastructure in the Midcontinent Region,” https://scripts.betterenergy.org/reports/GPI_DCFC_Analysis_July_2019.pdf.
[137]*Scaling EV charging infrastructure: Standards and interoperability.* s.l. : Charged Electric Vehicle Magazine, May 3, 2019.
[138]Center for Climate and Energy Solutions, *Strategic Planning to Implement Publicly Available EV Charging Stations: A Guide for Businesses and Policymakers.* 2015; Great Plains Institute for the Midcontinent Transportation Electrification Collaborative. Analytical White Paper: Overcoming Barriers to Expanding Fast Charging Infrastructure in the Midcontinent Region. July 2019.
[139] EIA, "State Electricity Profiles,” https://www.eia.gov/electricity/state/ (Accessed October 23, 2019) https://scripts.betterenergy.org/reports/GPI_DCFC_Analysis_July_2019.pdf.
[140] Tesla, “Supercharging, ”https (Accessed October 23, 2019)).
[141] Blink, “EV Charging Fees,” https://www.blinkcharging.com/ev-charging-fee (Accessed October 23, 2019)).
[142] Tyson, V., Eckerle Brazil, G. *Electric Vehicle Charging Station Permitting: Guidebook.* s.l. : California Governor’s Office of Business and Economic Development, January 6, 2020.
[143] Shahan, Z. “Shell Transforming Petrol Station To EV Charging Station In UK, Clean Technical,” https://cleantechnica.com/2020/02/07/shell-transforms-petrol-station-to-ev-charging-station-in-uk/.

[144] Miles Muller, “Reforming Rates for Electric Trucks, Buses, and Fast Chargers, NRDC Expert Blog, May 4, 2020 https://www.nrdc.org/experts/miles-muller/reforming-rates-electric-trucks-buses-fast-chargers.
[145] Muller, M. “Reforming Rates for Electric Trucks, Buses, and Fast Chargers, NRDC Expert Blog, May 4, 2020 https://www.nrdc.org/experts/miles-muller/reforming-rates-electric-trucks-buses-fast-chargers; San Diego Gas & Electric Company, “Transportation Electrification Framework: Proposed-Utility Side EV Infrastructure Tariff”, May 20, 2020; San Diego Gas & Electric Company,” R.18-12-006: Reply Comments of San Diego Gas & Electric Company on the Transportation Electrification Framework Overview,”. https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M335/K498/335498387.PDFhttps://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M335/K498/335498387.pdfhttps://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M335/K498/335498387.PDF.
[146] The International Council on Clean Transportation, “Lessons Learned on Early Electric Vehicle Fast charging Deployments,” https://theicct.org/sites/default/files/publications/ZEV_fast_charging_white_paper_final.pdf.
[147] Center for Climate and Energy Solutions, *Strategic Planning to Implement Publicly Available EV Charging Stations: A Guide for Businesses and Policymakers.* 2015.
[148] Make-ready infrastructure refers to all electrical infrastructure necessary to operate a charging station, including electrical conduits, wiring, and concrete work up to the charging station location.
[149] The International Council on Clean Transportation, “Lessons Learned on Early Electric Vehicle Fast charging Deployments,” https://theicct.org/sites/default/files/publications/ZEV_fast_charging_white_paper_final.pdf.
[150] Center for Climate and Energy Solutions, “Assessing the Electric Vehicle Charging Network in Washington State,” https://www.c2es.org/site/assets/uploads/2014/10/assessing-ev-charging-network-washington-state.pdf (Accessed October 24, 2019)).
[151] Seki, S., Nigro, N. “Electrifying Ride-Hail Services: A case Study on Maven Gig’s use of Chevrolet Bolt EVs,”Atlas Public Policy. http://evsharedmobility.org/wp-content/uploads/2018/09/Electrifying_Ride-Hail_Services.pdf.
[152] Autocar Pro News Desk, “Low-speed electric scooters make up for bulk of EV sales in India in FY2020,” Autocar Professional, https://www.autocarpro.in/author/profile/authorname/autocar-pro-news-desk/authorid/19 (Accessed April 20, 2020)).
[153] The International Council on Clean Transportation, “Lessons Learned on Early Electric Vehicle Fast charging Deployments,” https://theicct.org/sites/default/files/publications/ZEV_fast_charging_white_paper final.pdf.
[154] Center for Climate and Energy Solutions, *Strategic Planning to Implement Publicly Available EV Charging Stations:* A *Guide for Businesses and Policymakers,* 2015.
[155] Center for Climate and Energy Solutions, *Strategic Planning to Implement Publicly Available EV Charging Stations: A Guide for Businesses and Policymakers,* 2015.
[156]Atlas Public Policy, “Public Policies Map,” https://www.atlasevhub.com/materials/laws-regulations-and-legislation/ (Accessed October 23, 2020)).
[157] Tesla, “Supercharging,” https://www.tesla.com/support/supercharging (Accessed October 23, 2019);).
[158]Atlas Public Policy, “National EV Market Dashboard,” https://www.atlasevhub.com/materials/national-ev-sales/ (Accessed October 14, 2019)).
[159]Atlas Public Policy, “Public Policies Map Dashboard,” https://www.atlasevhub.com/materials/public-policy/ (Accessed October 14, 2019)).
[160] Center for Climate and Energy Solutions, *Strategic Planning to Implement Publicly Available EV Charging Stations: A Guide for Businesses and Policymakers.* 2015.
[161] U.S. Department of Energy, “Alternative Fuel Vehicle & Fueling Infrastructure Deployment Barriers & the Potential Role of Private Sector Financial Solutions,” https://www.c2es.org/site/assets/uploads/2014/04/afv_fueling-infrastructure-deployment-barriers.pdf.
[162] Atlas Public Policy, “Public Policies Map Dashboard,” https://www.atlasevhub.com/materials/public-policy/ (Accessed October 14, 2019)).
[163] US Department of Energy, “Alternative Fuels Data Center,” https://afdc.energy.gov/laws/arra.html (Accessed October 14, 2019)).
[164] Rocky Mountain Institute, "Reducing EV Charging Infrastructure Costs," https://rmi.org/insight/reducing-ev-charging-infrastructure-costs/.
[165] Center for Climate and Energy Solutions, *Strategic Planning to Implement Publicly Available EV Charging Stations: A Guide for Businesses and Policymakers.* 2015.
[166] Colorado General Assembly, *Modify Innovative Motor Vehicle Income Tax Credits*, HB19-1159, 2019 Regular Session.
[167] ChargePoint, “The Contractor's Guide to EV Ready Building Codes,” https://www.chargepoint.com/blog/contractors-guide-ev-ready-building-codes/ (Accessed October 23, 2019)).

[168] Alternative Fuels Data Center, “Plug-In Electric Vehicle Deployment Policy Tools: Zoning, Codes, and Parking Ordinances” https://afdc.energy.gov/bulletins/technology-bulletin-2015-08.html (Accessed October 23, 2019); Plautz, J. “Seattle passes EV readiness requirements,” https://www.utilitydive.com/news/seattle-passes-ev-readiness-requirements/554173/ (Accessed October 15, 2019)).
[169] Government of India Ministry of Power, https://powermin.nic.in/sites/default/files/webform/notices/scan0016%20%281%29.pdf.
[170]California Governor’s Office of Business and Economic, *Electric Vehicle Charging Station Permitting: Guidebook.* July 2019.
[171] UC Davis Institute of Transportation Studies, “Automakers and Policymakers May Be on a Path to Electric Vehicles; Consumers Aren't” https://its.ucdavis.edu/blog-post/automakers-policymakers-on-path-to-electric-vehicles-consumers-are-not/ (Accessed October 15, 2019)).
[172] Veloz, “We want Electric for all,” https://www.veloz.org.
[173] Innovation Center for Energy and Transportation, “Best EV 2018 annual report,” http://www.icet.org.cn/admin/upload/2019090259998221.pdf.
[174] Government Technology, “Millions Will Fund a Campaign Focused on Bolstering EVs in California,”https://www.govtech.com/fs/infrastructure/Millions-Will-Fund-a-Campaign-Focused-on-Bolstering-EVs-in-California.html.
[175] Forth mobility, “September Webinar: Dealership Engagement: Making the EV Case to Dealerships,” https://forthmobility.org/news/forth-webinar-series.
[176]The International Council on Clean Transportation, “Literature review of electric vehicle consumer awareness and outreach activities,” https://theicct.org/sites/default/files/publications/Consumer-EV-Awareness_ICCT_Working-Paper_23032017_vF.pdf.
[177] Make-ready infrastructure refers to all electrical infrastructure necessary to operate a charging station, including electrical conduits, wiring, and concrete work up to the charging station location.
[178] Georgetown Climate Center, “Utility Investment in Electric Vehicle Charging Infrastructure: Key Regulatory Considerations,” https://www.georgetownclimate.org/files/report/GCC-MJBA_Utility-Investment-in-EV-Charging-Infrastructure.pdf.
[179] Atlas Public Policy, “Utility Filings Dashboard,”https://www.atlasevhub.com/materials/electric-utility-filings/ (Accessed October 14, 2019)).
[180] Atlas Public Policy, “Utility Filings Dashboard,”https://www.atlasevhub.com/materials/electric-utility-filings/ (Accessed October 14, 2019)).
[181] Synapse Energy, “Electric Vehicles are Driving Electric Rates Down,”https://www.synapse-energy.com/sites/default/files/EV-Impacts-June-2019-18-122.pdf.
[182] Great Plains Institute for the Midcontinent Transportation Electrification Collaborative, “Analytical White Paper: Overcoming Barriers to Expanding Fast Charging Infrastructure in the Midcontinent Region,” https://scripts.betterenergy.org/reports/GPI_DCFC_Analysis_July_2019.pdf.
[183] Natural Resources Defense Council, “Reforming Rates for Electric Trucks, Buses & Fast Chargers,” https://www.nrdc.org/experts/miles-muller/reforming-rates-electric-trucks-buses-fast-chargers-0 (Accessed October 14, 2019)).
[184] ConEdison, “Consolidated Edison Company of New York. Electric Vehicle Charging Rewards,” https://www.coned.com/en/save-money/rebates-incentives-tax-credits/rebates-incentives-tax-credits-for-residential-customers/electric-vehicle-rewards.
[185] GreenTechMedia, “BMW's Plan to Optimize EV Charging with Renewables on the Grid,” https://www.greentechmedia.com/articles/read/bmw-optimizing-ev-charging-renewable-energy#gs.afcv3a (Accessed October 14, 2019)).
[186] The International Council on Clean Transportation, “Lessons Learned on Early Electric Vehicle Fast charging Deployments,” https://theicct.org/sites/default/files/publications/ZEV_fast_charging_white_paper_final.pdf.
[187] Atlas Public Policy, “Global Privat Investment Dashboard,” https://www.atlasevhub.com/materials/private-investment/ (Accessed October 14, 2019); Atlas Public Policy, “National EV Market Dashboard,”https://www.atlasevhub.com/materials/national-ev-sales/ (Accessed October 14, 2019)).
[188] Wired, “India Goes Electric with Battery-Swapping Rickshaws,” https://www.wired.com/story/india-sun-mobility-electric-rickshaw-bus-battery-swap/ (Accessed October 10, 2019)).
[189] Vineet, C.”Battery Swapping-Electric Vehicles, “Automotive Electronics, https://www.automotivelectronics.com/battery-swapping-electric-vehicles/ (Accessed October 15, 2019)).
[190] TeslaRati, “Tesla shuts down battery swap program in favor of Superchargers, for now,” https://www.teslarati.com/tesla-shuts-down-battery-swap-program-for-superchargers/.

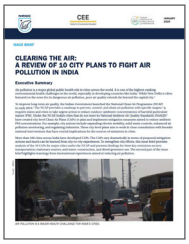
[191] The International Council on Clean Transportation, “Transitioning to Zero-Emission Heavy-Duty Freight Vehicles,” https://theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf.
[192] UC Davis Institute of Transportation Studies, “A Comparison of Zero-Emission Highway Trucking Technologies”. https://escholarship.org/uc/item/1584b5z9 (Accessed October 15, 2019)).
[193] Atlas Public Policy, “Public Agency Requests & Funding Awards” https://www.atlasevhub.com/materials/public-agency-requests-funding-awards/.
[194] Krok, A.” BMW launches 2019 5 Series plug-in hybrid wireless charging pilot in California, “Road Show, by CNET, https://www.cnet.com/roadshow/news/bmw-2019-5-series-phev-wireless-charging-pilot-california/; Fleet Carma, “EV Growing Pains: Electric vehicles are evolving and up-to date data is critical for demand-side management,” https://www.fleetcarma.com/ (Accessed October 15, 2019).

Resources Guide

India Focused Resources

Location is Everything: Approaches to Siting Electric Vehicle Charging Infrastructure for the Indian Context

https://www.nrdc.org/sites/default/files/location-everything-ev-issue-brief-20200127.pdf



Clearing the Air: A Review of 10 City Plans to Fight Air Pollution in India

https://www.nrdc.org/sites/default/files/10-city-plans-fight-air-pollution-india-202001.pdf

International Resources

Best Practices for commercial and Industrial EV Rates

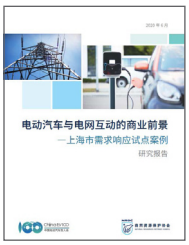
https://www.nrdc.org/sites/default/files/media-uploads/best-practices-commercial-industrial-ev-rates_0.pdf

Driving Out Pollution: How Utilities Can Accelerate the Market for Electric Vehicles

https://www.nrdc.org/sites/default/files/driving-out-pollution-report.pdf

Analysis on Developing a Healthy Charging Service Market for EVs in China

http://nrdc.cn/Public/uploads/2019-04-20/5cbb125a31059.pdf



Outlook on Business Models for EV-Grid Integration – Analysis on EV DR Pilot in Shanghai

http://nrdc.cn/Public/uploads/2020-06-02/5ed5f51a5972a.pdf

Highlighted Blogs

- **Mobilizing Finance for Electric Vehicle Charging in India, Sameer Kwatra, March 2020**
  https://www.nrdc.org/experts/sameer-kwatra/mobilizing-finance-electric-vehicle-charging-india
- **Moving Ahead with Electric Mobility in India, Charu Lata and Anjali Jaiswal, February 2020**
  https://www.nrdc.org/experts/anjali-jaiswal/moving-ahead-electric-mobility-india
- **For EV Charging Infrastructure, Location Is Everything, Anjali Jaiswal, Charu Lata and Sameer Kwatra, January 2020**
  https://www.nrdc.org/experts/sameer-kwatra/ev-charging-infrastructure-location-everything
- **Advancing EV Charging in Key Indian States, Anjali Jaiswal and Charu Lata, December 2019**
  https://www.nrdc.org/experts/anjali-jaiswal/advancing-ev-charging-key-indian-states
- **India Focus: Telangana Moves on Electric Mobility, Charu Lata, Anjali Jaiswal and Shabib Ansari, September 2019**
  https://www.nrdc.org/experts/anjali-jaiswal/india-focus-telangana-moves-electric-mobility
- **India Shifts Toward Electric Vehicles and Improved Mobility, Charu Lata and Anjali Jaiswal, July 2019**
  https://www.nrdc.org/experts/anjali-jaiswal/india-shifts-toward-electric-vehicles-and-improved-mobility